
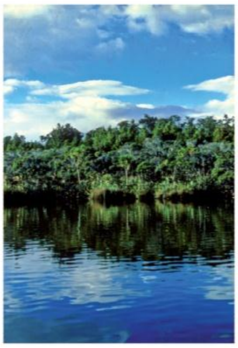

Modelling Economic Impacts of Nutrient Allocation Policies in Canterbury: Hinds Catchment





Landcare Research
Manaaki Whenua

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Adam Daigneault, Oshadhi Samarasinghe, Linda Lilburne

Landcare Research

Prepared for:

Ministry for the Environment

23 Kate Sheppard Place
PO Box 10362
Wellington 6143
New Zealand

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Landcare Research, 231 Morrin Road, St Johns, Private Bag 92170, Auckland 1142, New Zealand, Ph +64 9 574 4100, Fax +64 9 574 4101, www.landcareresearch.co.nz

Reviewed by:	*Approved for release by:*
Bob Frame Principal Scientist Landcare Research	Suzie Greenhalgh Portfolio Leader Enhancing Policy Development
Landcare Research Contract Report:	LC 1490

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Glossary

Advanced mitigation practices: Practices that modify farm systems to reduce nutrient losses. These changes often require some management alterations, capital purchases to upgrade existing infrastructure, and will have a varying impact on productivity and net farm revenue.

Base (current) practice: The average (representative) farm in the catchment as of June 2012**.**

Cap and trade: A regulation where a limit (cap) has been set on the nutrient discharge and sources are allowed to sell or 'trade' discharges to meet the defined limit.

Cash Farm Surplus: The amount of income accrued at the end of the year that can be directly reinvested in the farm. Revenue less costs of production. Includes debt servicing, plant replacement, and tax. Also includes cost of nutrient discharge allowance (NDA) and resource rent.

Command and control: A regulation that mandates what activities are legal and what are illegal.

Contaminant: Biological (e.g. bacterial and viral pathogens) or chemical (e.g. toxicants) introductions capable of producing an adverse effect in a waterbody.

Discharge: The release of contaminants into the environment either directly into water, or onto (or into) land.

Diffuse source discharge: Pollutants sourced from widespread or dispersed sources (e.g. from pasture runoff of animal wastes, fertiliser and sediments, as well as runoff of pollutants from paved surfaces in urban areas). Also called non-point source discharges.

Earnings before Interest and Tax (EBIT): Farm profits that excludes interests and taxes.

Good management practices (GMPs): Practices that are generally undertaken by the top 50% of farmers in the Hinds catchment as of June 2012. These practices typically reflect farmer compliance with supplier regulations and local government law.

Leaching: Process by which pollutants in and on soil are dissolved by rain or irrigation water and carried down into groundwater.

Limit: The maximum amount of nutrient, which allows an objective to be met. Also called 'cap' and used interchangeably in the report.

Load: The total amount of N being lost from the land surface through leaching or runoff. Measured as a rate in weight (i.e. mass) per unit time, expressed as either kilograms or tonnes per year (kgN/yr or tN/yr). Can also include point discharges. It is used interchangeably with N leaching total in the report as OVERSEER estimates do not differentiate between N losses through run off and leaching.

Mitigation: The moderation of a level of intensity through the implementation of changes in land management.

Net Farm Revenue: The key measurement of economic output from the land-based activities at the catchment scale in NZFARM. Based on farm earnings before interest and tax (EBIT). Includes additional costs of debt servicing and plant replacement for mitigation practices. Also includes cost of nutrient discharge allowance (NDA) and resource rent.

New Zealand Forest and Agriculture Regional Model (NZFARM): A catchment-scale economic land use model, that optimises total net farm revenue subject to economic, environmental and resource constraints. The model estimates the economic and environmental impacts of policy scenarios relative to a baseline (no policy).

Nitrate (NO_3): A highly soluble compound of nitrogen and oxygen.

Nitrogen (N): A chemical element. Common forms of nitrogen in water include ammonia and nitrate.

Nutrient: A substance, element or compound that organisms need to live and grow. Can be brought onto a farm in fertiliser, feed, and new stock. Nutrients can be lost through production, leaching, runoff, and into the atmosphere as gas.

Nutrient discharge allowance (NDA): Maximum amount of nutrient losses (kg/yr) allowed on a per ha basis. Can be traded across landowners, in some cases. Often called 'permit' in economics literature.

Point source discharge: Discharge of contaminants into a waterbody from a single fixed point, such as a pipe or drain (e.g. from the likes of sewerage, factory and dairy shed outfalls).

Run-off: Water moving overland, carrying fine sediment and dissolved pollutants.

Target: Limit which must be met at a defined time in the future.

Executive Summary

In Canterbury, a collaborative planning process, working with local communities, is being used to set water quality limits. Under the Canterbury Water Management Strategy (CWMS), the region is divided into 10 water management zones (WMZ). A joint regional / district council committee, consisting of local people with a range of views on water management, has been established in each zone.

The Hinds catchment, one of the catchments within the Ashburton WMZ, is the focus of this report. The catchment is currently primarily sheep and beef, dairy, and arable. However, the area is expected to intensify further with the expansion of irrigation through extensions to the Rangitata Diversion Race (RDR) in the catchment and is expected to bring more dairy and dairy support into the catchment.

The Hinds Zone Committee is tasked with determining water quality limits for the Hinds catchment. At the time of this report, they are considering a 90% aquatic species protection target to ensure, among other things, there is a viable trout fishery in the Hinds River and an 80% species protection target for lowland streams. For this study analysis focuses on a water quality objective of achieving 80% species protection in the Hinds River and streams near the coast, to achieve the national bottom line objective. To achieve this, an average nitrogen level below 6.9 mg nitrate-N (N) per litre is needed in the streams and rivers of the catchment. Environment Canterbury (ECan) estimates that to meet these species protection targets the total nitrogen leaching in the catchment has to be 30% lower than the N leaching from current land use. Additional water from the alpine rivers would also need to be released into the catchment to dilute N concentrations in streams and rivers. After the new irrigation comes on-line a 45% N leaching reduction target will be required.

This report uses an economic land use model, NZFARM, to assess the economic and environmental impacts of different policy scenarios to reduce nutrient losses from diffuse sources in the Hinds catchment. NZFARM is designed for detailed modelling of land uses at a catchment scale. It enables the consistent assessment of multiple policy scenarios against a given set of economic and environmental outputs by estimating and comparing the relative changes in these outputs between scenarios. NZFARM includes several management options for managing N leaching at the farm-level, such as reducing nitrogen fertiliser application, improving irrigation efficiency, wintering off dairy cows, stream fencing and riparian planting. While the list of feasible farm management options is extensive, we do not necessarily include all possible nutrient sources or options to mitigate nutrient losses from diffuse sources into waterways. The results from NZFARM are reliant on input data (eg, farm budgets, mitigation costs, and N leaching rates) from external sources and may vary should different input data is used. NZFARM also does not account for the broader impacts of changes in land use and land management beyond the farm gate.

For this analysis, the model compares each policy scenario to a ‘no policy’ baseline that assumes an extra 30,000 ha of new irrigation from the RDR and that there is no nutrient reduction policy in place. NZFARM estimates that the total N leaching for the no policy baseline is 5,860 tN/yr, and the annual N leaching total under a 45% N reduction target is 3,240 tN/yr or 23.9 kgN/ha/yr. The modelled policy scenarios, outlined in Table 1, included requiring landowners to implement improved land management practices, regulating the total N leached within the catchment and allocating this limit to individual landowners (ie, allocating nutrient discharge allowances (NDAs)), allowing the trading of NDAs between landowners, and charging a resource rent on N leaching. The scenarios that restrict or cap the N leaching within the catchment consider several allocation options (eg, averaging, natural capital, grandparenting, equal, nutrient vulnerability and auction) to distribute the cap between N leaching sources in the catchment, primarily landowners. The scenarios assessed in this report were determined by ECan and the Ministry for the Environment (MfE).

Table 1: Overview of NZFARM Nutrient Reduction Policy Scenarios, Hinds Catchment

Policy Scenario	Description	Allocation Approach	Allocation (kgN/ha)	Trading Regime
Baseline (No Policy)	There is no nutrient reduction policy in the catchment and an additional 30,000 ha of new irrigation area in the catchment increases the area of dairy, dairy support, and arable land.	n/a	n/a	n/a
Improving Land Management Practices				
Advanced Mitigation 1 (AM1)	All arable and pastoral landowners required to implement an advanced mitigation 1 bundle of management practices.	None	n/a	None
Farm-Specific Caps (no trading)				
Average Allocation	Each landowner is allocated the same number of NDAs regardless of their location in the catchment or their land use.	Average	23.9	None
Natural Capital Allocation	Each landowner is allocated NDAs based on a land use capability classification (which is a proxy for natural capital) where more productive land is allocated more NDAs.	Natural capital as defined in Lilburne et al (2013)	2.5 to 33.1	None
Catchment-wide Cap and Trade				
Grandparent Allocation + Trading	Each landowner is freely allocated NDAs based on a 45% reduction in N leaching from their existing (or reference year) N leaching rate.	Grandparenting	0 to 47.6 (average of 23.9)	Catchment-wide
Nutrient Vulnerability Allocation + Trading	Each landowner is freely allocated NDAs using a nutrient vulnerability classification based on the nutrient filtering capacity of the soil and higher leaching land is allocated more NDAs.	Nutrient vulnerability class as defined in Webb et al (2010)	10.3 to 27.7	Catchment-wide
Auction Allocation + Trading	NDAs are allocated using an auction mechanism.	Auction	Varies (average of 23.9)	Catchment-wide
Hybrid Approach				
Grandparent Allocation + Resource Rent	Each landowner is allocated NDAs based on a 45% reduction in N leaching from their existing (or reference year) N leaching rate and have to pay an annual resource rent of $2.50/kg N leached.	Grandparenting	0 to 47.6 (average of 23.9)	Catchment-wide
Equal Allocation + Trading	Landowners are allocated NDAs based on whether their land is classified as high or low productivity land and all land within each class is allocated the same number of NDAs. Land in the higher productivity class is allocated more NDAs.	Land productivity class defined using Lilburne and Webb (2012)	2.0 to 24.8	Restricted to same productive land zones
Catchment Club Allocation + Trading	Landowners within each irrigation scheme (catchment club) are allocated NDAs based on a 45% reduction in N leaching from their existing (or reference year) N leaching rate and allowed to trade. Those landowners outside the clubs are allocated an average allocation for the land area that falls outside of the club and not allowed to trade.	Grandparenting (club) and average (all others)	15.9 to 47.6	Restricted to catchment club zones

Catchment Results

For each policy scenario, the mitigation costs of achieving the nutrient reduction target and the resulting changes in net farm revenue, cash farm surplus, council revenue, N leaching, P loss, GHG emissions, and the average cost of N abatement are tracked. A summary of the key outputs for each policy scenario is listed in Table 2. NZFARM estimates reported here are highly dependent on input data provided by McFarlane Rural Business Ltd (MRB, 2013). If different sources indicate higher mitigation costs compared to the costs provided by MRB, meeting the 45% N reduction target could become more costly.

Table 2: NZFARM Policy Analysis Summary, Hinds Catchment

Policy Scenario	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Annual Estimated Values							
Baseline (no policy)	$338.0	$79.4	$0.0	5,860	92	791,631	$0.00
Advanced Mitigation 1	$324.9	$70.7	$0.0	3,570	81	709,995	$5.70
Average Allocation	$291.8	$63.3	$0.0	2,881	79	652,004	$15.50
Natural Capital Allocation	$291.0	$61.9	$0.0	2,912	78	669,373	$15.90
Grandparent Allocation + Trading	$305.3	$67.6	$0.0	3,240	80	706,240	$12.50
Nutrient Vulnerability Allocation + Trading	$306.0	$68.5	$0.0	3,240	84	752,187	$12.20
Auction Allocation + Trading	$233.3	-$4.5	$72.1	3,240	80	706,209	$40.00
Grandparent Allocation + Resource Rent	$297.2	$59.5	$8.1	3,240	80	706,240	$15.60
Equal Allocation + Trading	$308.8	$69.6	$0.0	3,240	84	721,309	$11.10
Catchment Club Allocation + Trading	$299.0	$65.2	$0.0	3,135	76	678,034	$14.30
Percent Change From Baseline							
Advanced Mitigation 1	-4%	-11%	n/a	-39%	-12%	-10%	n/a
Average Allocation	-14%	-20%	n/a	-51%	-14%	-18%	n/a
Natural Capital Allocation	-14%	-22%	n/a	-50%	-16%	-15%	n/a
Grandparent Allocation + Trading	-10%	-15%	n/a	-45%	-13%	-11%	n/a
Nutrient Vulnerability Allocation + Trading	-9%	-14%	n/a	-45%	-9%	-5%	n/a
Auction Allocation + Trading	-31%	-106%	n/a	-45%	-13%	-11%	n/a
Grandparent Allocation + Resource Rent	-12%	-25%	n/a	-45%	-13%	-11%	n/a
Equal Allocation + Trading	-9%	-12%	n/a	-45%	-9%	-9%	n/a
Catchment Club Allocation + Trading	-12%	-18%	n/a	-46%	-18%	-14%	n/a

The 45% N leaching reduction target is relatively high (Figure 1) and while most policy scenarios do meet the target, some do not. All scenarios modelled also experience a decrease in net catchment revenue. Where trading was allowed, the distribution of N leaching between the enterprises changed, depending on the scenario (Figure 2).

Figure 1: Total N leaching (tN/yr) and net farm revenue (million $/yr) from each policy scenario

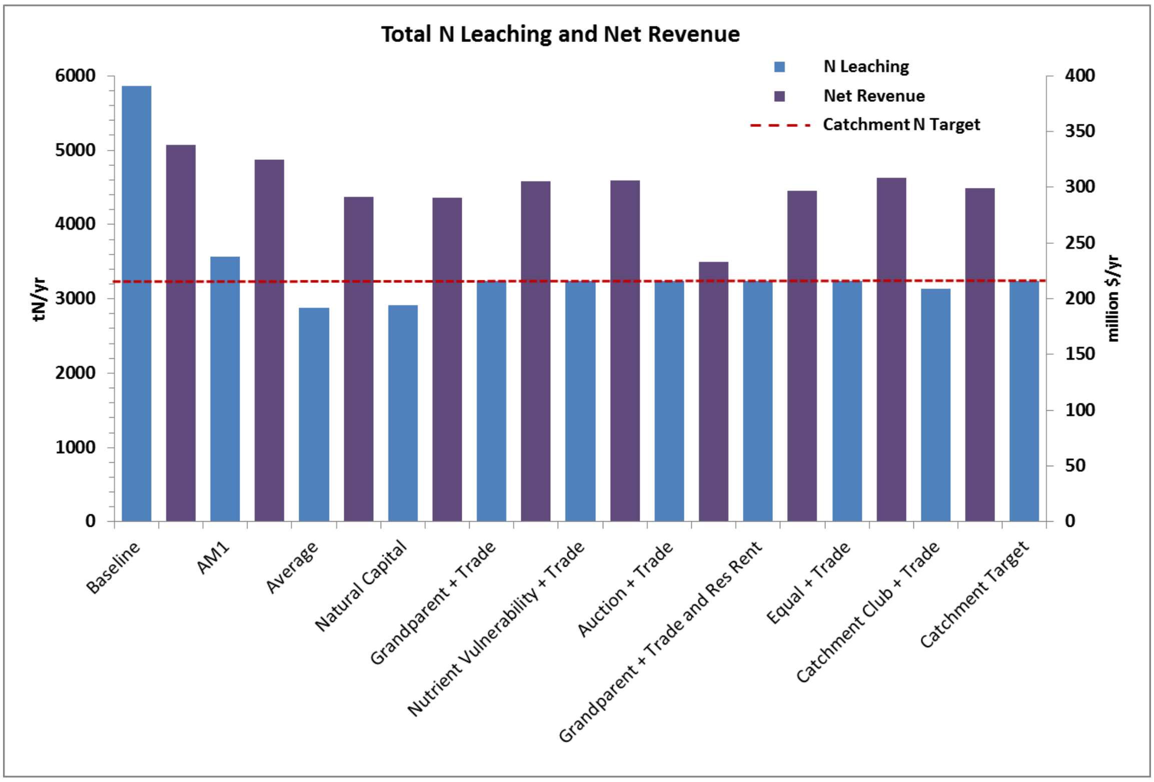
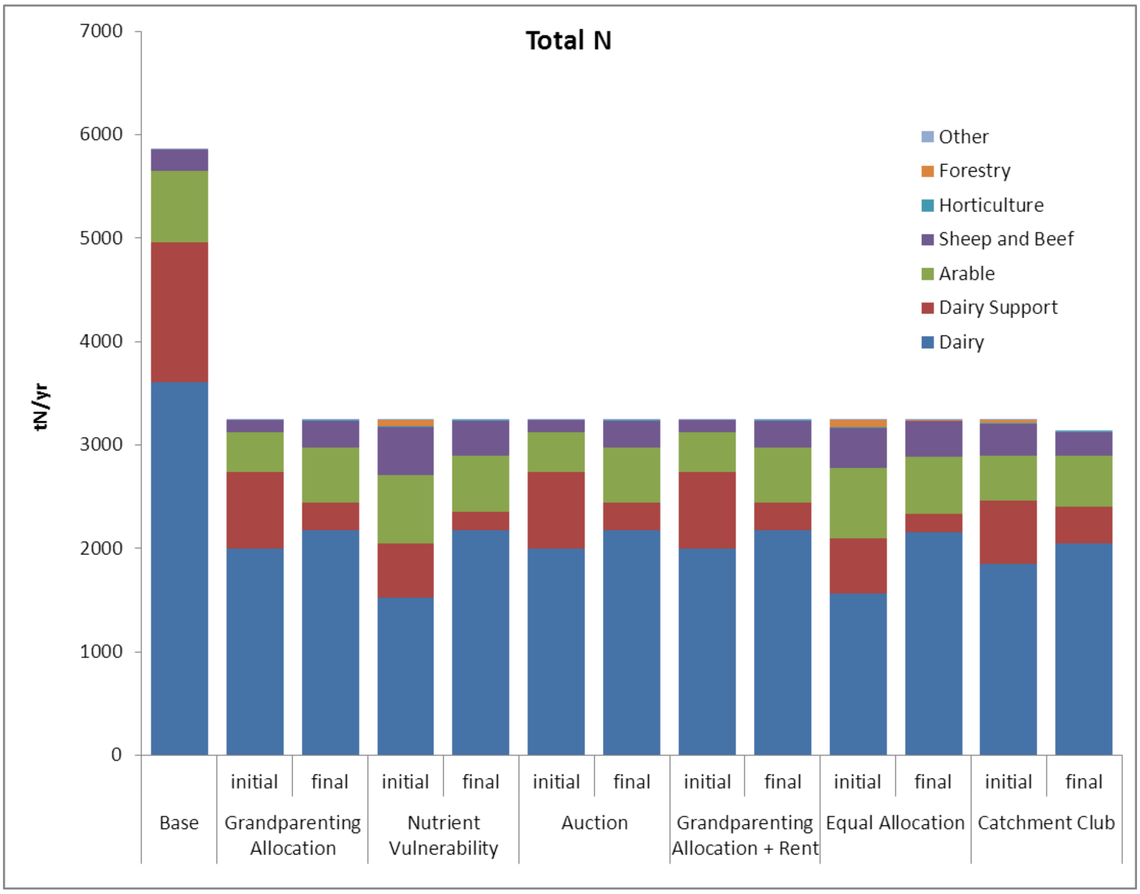


Figure 2: Initial N allocation and final N leaching (tN/yr) for the scenarios with trading



Improving land management practices

The modelling assumed that all pastoral and arable landowners must implement the entire set of practices listed in the advanced mitigation 1 scenario. This resulted in a 39% reduction in total N leaching with a 4% loss in net revenue (Table 1). As the 45% N reduction target is not met additional policy instruments would be required to achieve the remaining reductions.

The biggest challenge with a practice-based policy, such as requiring the adoption of a set of mitigation practices, is that while it may be effective at getting practice change it may not achieve any environmental improvement. Only tracking practice uptake and not the reduction in N leaching as a result of any change in the practices and overall land management could mean that total N leaching increases as landowners continue to intensify their production (eg by changing land use or stocking rates) alongside adopting practices to reduce N leaching.

Farm-specific caps

Farm-specific caps involve the establishment of a catchment-wide cap and then the allocation of this cap among landowners. Landowners are allowed to leach no more than the specified N leaching limit for their land. This limit is articulated in terms of nitrogen discharge allowances (NDAs). Landowners can choose any land use or management practice to stay within their allocated NDAs but they are not allowed to trade their NDAs. The 45% reduction target was used to set the overall N leaching cap from land-based diffuse sources. Two allocation approaches were then modelled: averaging and natural capital. Averaging allocates the NDAs uniformly (on a per hectare basis) across the catchment regardless of their location in the catchment or their land use. The natural capital approach allocates NDAs based on land use capability (LUC) classes across the catchment. Land with lower LUC classes (i.e. is more productive) is allocated more NDAs on a per hectare basis than land on higher LUC classes.

In the Hinds catchment both the averaging and natural capital allocation approaches reduce net revenue by 14%. These two approaches achieved respectively a 51% and 50% decrease in N leaching in the catchment. As landowners are not able to trade any excess NDAs, more reductions are achieved than the specified target of 45% below the baseline. Under averaging, more intensive landowners, such as dairy and dairy support, on the high leaching soils face higher costs than those on low leaching soils. Those enterprises on the high leaching soils may have to reduce their N leaching by as much as 75% to meet their regulated limit.

Overall, arable land uses experience a greater reduction in net revenue under averaging (accounting for both the costs of land moving out of arable land uses and the cost of implementing new management practices); and dairy support fares better under averaging in terms of net revenue. All other enterprises experience similar changes in revenue under both allocation approaches (Figures 3 and 4).

Figure 3: Net farm revenue by enterprise for each policy scenario

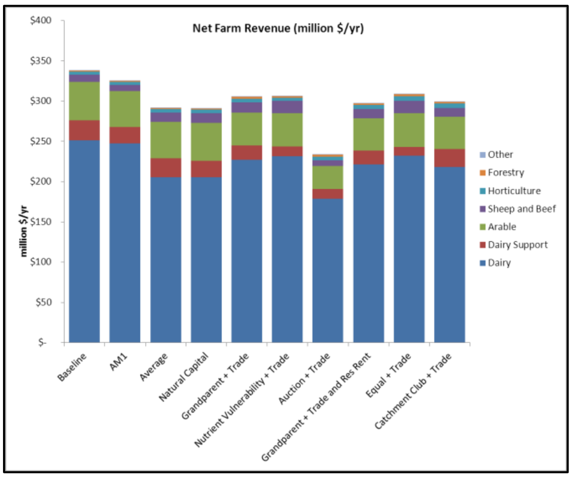
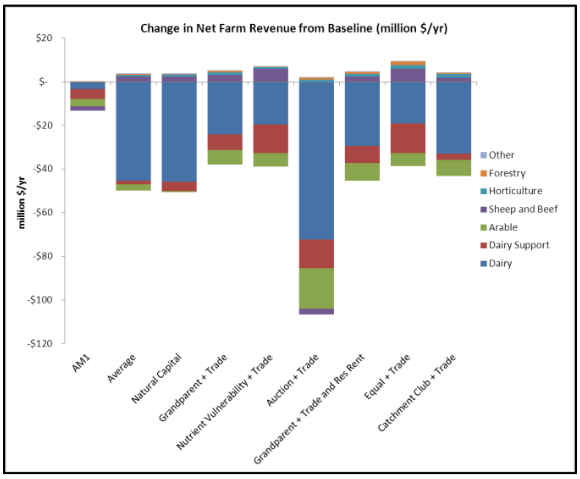


Figure 4: Change in net farm revenue from the Baseline by enterprise for each policy scenario



Cap and trade Policies

Cap and trade involves the establishment of a catchment cap for N leaching, the allocation of this cap to landowners in the form of NDAs (same as in the farm-specific caps scenario) and then allows the trading of NDAs between landowners. Cap and trade is premised on landowners having differing costs to reduce nutrients depending on their size, location, scale, management, and overall efficiency. As landowners can choose the most appropriate N reduction management practices for their context, they can also increase, maintain, or decrease their N leaching rates, as long as they hold sufficient NDAs to cover their N leaching. If they have excess NDAs they can sell them, while if they do not have enough NDAs they can purchase them from another landowner. Landowners can have excess NDAs either through being initially allocated them (ie, get a 'windfall gain') or by reducing their N leaching below what they are required to. The latter is likely to occur when the price of an NDA is higher than the cost of implementing a nutrient mitigation practice(s) for that landowner. Theoretically, cap and trade is more flexible and cost-effective than the policies discussed earlier that require all landowners to implement certain land management practices or meet individual targets.

The administrative costs of cap and trade are the same as for the farm-specific cap scenario except for any costs associated with registering trades and changing the NDAs for each landholding to reflect any transfers that have taken place. More sophisticated infrastructure such as marketplaces can also be developed but these are not essential for the operation of a trading programme.

As with the farm-specific cap scenarios, the allocation process for cap and trade is also likely to be highly contentious. Three allocation approaches were modelled under the assumption that NDAs could be traded between landowners across the entire catchment: grandparenting, nutrient vulnerability, and auctioning the allowances. With grandparenting each landowner is allocated NDAs based on a 45% reduction in N leaching from their existing (or reference year) N leaching rate, while nutrient vulnerability allocates NDAs using a nutrient vulnerability classification based on the nutrient filtering capacity of the soil. The auctioning of allowances is assumed to occur once per annum, to establish the initial allocation of allowances to landowners. Note that NDAs were freely allocated to landowners for the grandparenting and nutrient vulnerability approaches, but that the auction approach required that all NDAs be acquired at market value (ie, zero free allocation).

At the catchment scale, grandparenting and nutrient vulnerability allocation approaches with trading reduced net revenue by 9–10%. These approaches freely allocated NDAs to landowners. Auctioning allowances, where landowners had to purchase NDAs, resulted in a 31% reduction in net revenue across the catchment. All scenarios achieved the 45% N reduction target.

For this catchment net revenue for dairy decreases more under grandparenting than the nutrient vulnerability allocation scenario. In the nutrient vulnerability scenario net revenue for dairy support decreases more than under grandparenting, while the increase in net revenue for sheep and beef is greater than with grandparenting (Figures 3 and 4).

Auctioning generates revenue for the regional council. The average price of the auctioned allowances is approximately $22/kg N, generating about $72 million for the council. These funds could be re-distributed back to landowners and the community in a number of ways, eg, reducing rates, financing mitigation practices that are beyond a single landowner (eg, large wetland), investing in infrastructure or providing cost-share (or equivalent) payments to farmers to assist and incentivise the implementation of more costly mitigation practices.

Hybrid Policy Approaches

Three ‘hybrid’ policy scenarios were modelled. One scenario combined cap and trade with a resource rental charge. The second scenario allocated NDAs equally to landowners in the same land productivity class and restricted trading of NDAs to these specific classes. The final scenario involved cap and trade in part of the catchment and a farm-specific cap in the rest of the catchment (called a catchment club scenario). These scenarios are considered because they have the potential to reduce the administrative burden of policy by either limiting the geographic scope of trading or by creating an additional source of income for the council.

The resource rental charge is similar to a N tax on each kg of N leached. While this charge is collected by the council, the council can re-distribute these funds back to landowners and the community if they so choose. Determining the charge price is challenging and there may be some political resistance by landowners to paying an additional charge on top of the costs to meet their nutrient reduction targets. This modelled policy scenario combined the catchment-wide cap and trade with grandparenting allocation approach with a $2.50/kg N resource rental charge. This reduced net catchment revenue by 12%, while generating approximately $8.1 million per annum for the council from the resource rental charge.

The equal allocation scenario is a variant of the averaging and natural capital allocation approaches. The catchment is divided into high and low productive land, with the high productive land being allocated more NDAs on a per hectare basis than low productive land. NDAs can only be traded within the same land productivity class. About 95% of land in the catchment was classified as high productivity land, so results are similar to the catchment-wide cap and trade scenarios. Net revenue was estimated to be reduced by 9% and it achieved the 45% N reduction target.

The catchment club scenario divides the catchment into three zones, two of which correspond to the Mayfield-Hinds and Valetta irrigation scheme areas. Cap and trade is only allowed in the irrigation scheme zones. In the irrigation scheme zones the allowances are allocated using a grandparenting approach, while averaging is used for the remaining zone which disallows trading.

Depending on how the catchment club policy is designed and how the catchment clubs are delineated in the catchment it may be administratively less burdensome for the council. If each club is assigned and consented for an aggregate number of N leaching allowances then the council only has to monitor that the club is in compliance and not the individual landowners in the club. It would be the responsibility of the club to further distribute the allowances to landowners within the club and administer any trades. The landowners in the areas outside the irrigation schemes would still need individually to demonstrate compliance with their individual NDA allocation. This assumes that no overarching entity is created to manage this club as there is no trading of allowances and therefore no need for such an entity. The reduced size of nutrient market within each club, however, could increase the price paid for traded NDAs. Clubs may also have other advantages over the catchment –wide cap and trade scenarios. The club structure reduces the size of the zone within which trades can occur, thereby potentially reducing the occurrence of ‘hotspots’. Hotspots are localised areas of lower water quality resulting from trades which increase N leaching upstream. It may also be easier for buyers and sellers to locate each other within the smaller geographic area of the club and if there is an overarching entity that manages the club.

The catchment club results in a decrease in net revenue of about 12% across the catchment. This is slightly larger than the impact of cap and trade with grandparenting scenario, demonstrating that the smaller trading zones may indeed have increased the cost of the policy. However, the farm-specific cap with an average allocation scenario (no trading) reduces net revenue by 14%. So, policy scenarios that offer some greater flexibility through trading appear less costly.

There are some notably different enterprise-level impacts for the hybrid scenarios. Dairy support fares worst under equal allocation and best under a catchment club while dairy fares the best under equal allocation, when comparing the net farm revenue losses relative to the baseline (Figures 3 and 4).

Summary of findings

This report provides an assessment of the impacts of four types of policy approaches for reducing nutrients from diffuse sources in the Hinds Catchment. These include: improving land management practices, farm specific caps, cap and trade and hybrid approaches. The analysis shows which policy approaches are able to meet the 45% N leaching reduction target, how each scenario affects catchment net revenue and what land use and land management change may result from each scenario. The analysis highlights some key findings that should form any consideration about the policy scenarios that could be pursued by ECan in the Hinds catchment.

The results from NZFARM are based on the best data and information available for the Hinds catchment at the time this report was written. It should be noted that the costs of meeting the 45% N reduction target could differ if alternative data sources indicate different costs and/or leaching rates. As NZFARM uses representative farms, some landowners in the catchment may actually face higher or lower costs than what are modelled using these representative farms. This analysis also does not account for the broader impacts of changes in land use and land management beyond the farm gate. The flow-on effects from some of the policies investigated in this report could produce a significant change in regional employment and GDP, as well as social and cultural impacts. These aspects were not intended to be a part of this report. Thus, the estimates presented in this report provide just a subset of possible metrics that could be used to determine the best policy to manage nutrients at the catchment-level. Farm- (eg, MRB 2013) and regional- (eg, Olubode-Awosola & Paragahawewa 2013) level analyses of economic impacts of nutrient reduction policies should also be considered along with the NZFARM estimates when determining the most appropriate policy to implement in the catchment. A list of key caveats, assumptions, and limitations for this analysis is included in Box 1.

The analysis demonstrates that improving land management practices, as shown in AM1 scenario, will not achieve the 45% N leaching reduction target suggested for the Hinds catchment. Further, there could be additional intensification of production in the catchment as total N leaching is not capped. More intensive land uses and management is possible as long as landowners implement improved land management practices. This could therefore increase overall N leaching.

The administrative costs for the scenarios that establish N leaching catchment caps are similar. There are one-time costs associated with establishing the catchment caps, allocating that cap to individual sources and consenting/permitting those sources, developing a database to track landowner compliance against their allocated NDA, and education and outreach to landowners on the new policy. There are also on-going administrative costs for the annual processing of landowner (or perhaps ‘club’) compliance reports (or equivalent) and any compliance and monitoring checks. For scenarios with trading there is the additional one-time expense of developing infrastructure to support trading (such as a marketplace) if that is deemed necessary and any on-going processing costs for changes to consents related to the trading of allowances.

It should be noted that all scenarios with catchment caps and the allocation of NDAs will require the benchmarking of all land in the catchment. This is to determine whether a landowner is in compliance or not with their allocated NDAs.

Some scenarios generate revenue for the council, principally the use of an auction mechanism to allocate NDAs and the resource rent charge. These could be poorly perceived by landowners because of the extra financial burden above and beyond their costs to meet their allocated N leaching limits. However, the generated revenue could be re-distributed back to landowners and the community to help ease the challenges with meeting an overall 45% N leaching reduction target and individual N leaching limits.

Box 1: Key caveats, assumptions, and limitations of this analysis

- Our economic analysis largely depends on the datasets and estimates provided by McFarlane Rural Business Ltd (MRB, June 2013) and Environment Canterbury. Estimates derived from other data sources may provide different results for the same catchment. Thus, the tools and analysis presented here should be used in conjunction with other information during the decision making process.
- This analysis includes an extensive list of N leaching mitigation strategies that could be implemented in the Hinds catchment. However, including additional mitigation options could lower both the overall cost of the policy and the cost to individual landowners.
- NZFARM does not explicitly account for all administrative and transaction costs of the various policies. Doing so could alter the estimates for the distributional impacts to farmers, land use change, and overall cost of the different policies.
- The modelling exercise assumes that technology, climate, input costs, and output prices are all constant for the duration of the policy, since the aim of this modelling exercise is to focus on comparing a range of policy scenarios at a given point in time.
- NZFARM tracks changes in N leaching and P loss. We acknowledge that there are other important factors and quantitative measures to consider beyond these nutrients for assessing changes in water quality, such as sediment and microbial pathogens.

1 Introduction

The Canterbury Region, New Zealand, has a diverse range of aquatic environments from mountain springs to coastal estuaries, connected by an intricate network of rivers, lakes, wetlands, estuaries and groundwater systems. Water is a pivotal resource for recreation, tourism, energy and industry. It is a source of life and food, and it is a central part of everyday life.

Most of the Canterbury's surface water and groundwater resources are of high quality, and many water bodies are still largely in their natural state. Human activities, though, have greatly increased the concentrations and types of contaminants entering Canterbury's water bodies. The impact of these activities on water quality varies throughout the region. Diffuse discharges, primarily nutrients leaching from intensive land-use, are the principal cause of declining water quality in many parts of the region (Ministry for the Environment, 2007; Land and Water Forum, 2010; Environment Canterbury, 2011).

Water quality in the Hinds catchments has been impacted by nutrients, primarily sourced from agriculture, specifically total nitrogen. Agricultural and use intensification in recent years has increased pressure on the catchment's water bodies. The number of dairy cattle in the Canterbury Region as a whole has increased by over four times in the past 20 years. A significant amount of land in the catchment has been converted to dairy farming from sheep and beef and arable. This intensification is expected to continue with, for example, the expansion of irrigation through extensions to the Rangitata Diversion Race (RDR) in the Hinds catchment[1].

The National Policy for Freshwater Management 2011 requires regional councils to set water quality limits, within a specified timeframe, to address over allocated water resources. Under the Canterbury Water Management Strategy (CWMS), the region has been divided into 10 water management zones. The CWMS requires water quality limits to be set within a specified timeframe. The strategy contains a suite of environmental, social, cultural and economic targets, including setting nutrient leaching limits, which must be achieved collectively over the next 5, 10 and 20 years. Zone committees have been established in each zone to develop, in conjunction with the local communities, a way of achieving the strategy's environmental and economic outcomes.

This study assesses the economic implications of various options to set nitrogen limits in the Hinds Catchment in Canterbury. The Hinds Zone Committee, as it sets limits, is considering a target of 90% aquatic species protection to ensure, amongst other things, a viable trout fishery in the Hinds River and an 80% species protection for the lowland streams. For this study the analysis is focused on a water quality objective of achieving 80% species protection in the Hinds River and streams near the coast, to achieve the national bottom line objective. This corresponds to an average nitrogen level below 6.9 mg nitrate-N (referred to as N in this report) per litre. To achieve this water quality objective, Environment Canterbury (ECan) estimates that the total N leaching has to be reduced by 30% from the total N leached under current land uses, coupled with additional water from the alpine rivers released into the catchment. This N reduction is approximately 45% lower than the estimated total N leaching if the new irrigation comes online.

[1] http://ecan.govt.nz/publications/Plans/draft-devlpmnt-scenario.pdf

The economic costs of reducing N leaching total in the Hinds catchment are estimated using a catchment-level economic model, the New Zealand Forest and Agricultural Regional Model (NZFARM). NZFARM is a catchment scale economic land use model (Daigneault et al., 2012a, 2012b; Greenhalgh et al., 2012). Its primary use is to provide decision-makers with information on the economic impacts of environmental policy as well as how a policy aimed at one environmental issue could affect other environmental factors. It can be used to assess how changes in technology, commodity supply or demand, resource constraints, or farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decisions-makers and rural landowners. NZFARM is designed for detailed modelling of land uses at a catchment scale.

NZFARM includes several management options for managing N leaching at the farm-level, such as reducing nitrogen fertiliser application, improving irrigation efficiency, wintering off dairy cows, stream fencing and riparian planting. While the list of feasible farm management options is extensive, we do not necessarily include all possible nutrient sources or options to mitigate nutrient losses from diffuse sources into waterways. In addition, while we do track N leaching from point sources within the catchment, this analysis does not model any nutrient mitigation that could be undertaken by point sources. Including additional management options and sources of mitigation would potentially reduce the estimated costs of each of the policies assessed in this report. An overview of the key components of the NZFARM for the current parameterisation of the Hinds Catchment is shown in Table 2.

Table 2: Overview of NZFARM for modelling Hinds Catchment

Scale	Enterprise	Farm Management	Economic Output	Environmental Output
Spatial: Sub-regions (NZFARM zones) Temporal: 5 year time steps	Dairy, dairy support sheep and beef, arable, exotic forestry, native forest	Nutrient budgeting, effluent management compliance, stock exclusion, variable rate irrigation and fertiliser application, soil moisture monitoring, nitrate inhibitor (DCD) application, irrigation upgrade, feed pads, reduce stock and fertiliser	Net farm revenue Cash farm surplus Commodity production Cost of abatement for N mitigation	N leaching P loss GHG emissions Water use for irrigation

We consider a number of policies that could reduce nutrient losses from diffuse sources. All the policy scenarios and allocation options included in this report were determined by Ministry for the Environment (MfE) and ECan. Core policies include (1) requiring the adoption of specific ‘good’ management practices and ‘advanced’ mitigation practices, (2) requiring individual landowners to meet specific maximum N leaching targets, or (3) setting a catchment-wide cap and allocating nutrient discharge allowances (NDAs) that landowners are able to trade between each other, and (4) a hybrid of all these approaches.

For each policy scenario, we report the resulting changes in farm profit,[2] represented by net revenues in the catchment, as well as cash farm surplus relative to the modelled baseline scenario that assumes the continuation of business as usual land management practices (and N leaching) in the absence of any nutrient reduction policy. We also estimate changes in key environmental outputs, namely N leaching, phosphorous (P) loss, and greenhouse gas (GHG) emissions. Where appropriate, the estimated land-use and land management changes resulting from each scenario are also reported.

There are several other important factors and metrics to consider for a policy assessment beyond estimating the economic impacts of reducing N leaching from diffuse sources. These are outside the scope of this report. Sediment and microbial pathogens, for example, can have a strong influence on water quality. The economic and biophysical model used for this analysis is currently not able to assess the impacts of these factors from changes in land use and/or land management. However, the on-farm land management practices and options to mitigate N leaching often reduce micro-organism and sediment contamination as well. The model used in this analysis also estimates changes in P loss and GHG emissions, thereby highlighting some of the other “co-benefits” that could arise from implementing policies that promote the reduction of nutrient discharges from diffuse sources. Acknowledging this concept of co-benefits is important as there are often multiple pollutants and policies being discussed simultaneously at the central government and regional council level.

This analysis also does not account for the broader impacts of changes in land use and land management beyond the farm gate. The flow-on effects from some of the policies investigated in this report could produce a significant change in regional employment and GDP. As NZFARM uses representative farms, some landowners in the catchment may actually face higher or lower costs than what are modelled using these representative farms. There could also be social and cultural impacts as well. These aspects were not intended to be a part of this report. Thus, the estimates presented in this report provide just a subset of possible metrics that could be used to determine the best policy to manage nutrients at the catchment-level. Farm and regional- (eg, Olubode-Awosola & Paragahawewa 2013) level analyses of economic impacts of nutrient reduction policies should be considered along with NZFARM estimates when determining the most appropriate policy for the Hinds catchment. A list of key caveats, assumptions, and limitations for this analysis is included in Box 1.

The report is organised as follows. First we discuss the methodology behind the NZFARM. Next we provide an overview of the various nutrient reduction policies that are considered in this report. Third, we describe the modelled baseline that is the basis of comparison for the policy scenario analysis. Then we present the estimated economic and environmental impacts of the different policies on landowners in Hinds catchment. Finally, we summarise our findings and present some conclusions. The main report is accompanied by a series of appendices that contain greater details on the economic model, data, and detailed results that support our policy scenario analysis.

[2] Base management (no mitigation) farm profit is measured as annual earnings before interest and taxes (EBIT), or the net revenue earned from output sales less fixed and variable farm expenses. Net farm revenue where GMP and AM are adopted also accounts for the increased debt servicing and plant replacement costs above the baseline management. Cash farm surplus is estimated as EBIT less the annual costs of debt servicing, capital purchases, and taxes.

Box 2: Key caveats, assumptions, and limitations of this analysis

- Our economic analysis largely depends on the datasets and estimates provided by McFarlane Rural Business Ltd (MRB, June 2013) and Environment Canterbury. Estimates derived from other data sources may provide different results for the same catchment. Thus, the tools and analysis presented here should be used in conjunction with other information during the decision making process.
- This analysis includes an extensive list of N leaching mitigation strategies that could be implemented in the Hinds catchment. However, including additional mitigation options could lower both the overall cost of the policy and the cost to individual landowners.
- NZFARM does not explicitly account for all administrative and transaction costs of the various policies. Doing so could alter the estimates for the distributional impacts to farmers, land use change, and overall cost of the different policies.
- The modelling exercise assumes that technology, climate, input costs, and output prices are all constant for the duration of the policy, since the aim of this modelling exercise is to focus on comparing a range of policy scenarios at a given point in time.
- NZFARM tracks changes in N leaching and P loss. We acknowledge that there are other important factors and quantitative measures to consider beyond these nutrients for assessing changes in water quality, such as sediment and microbial pathogens.

2 Methodology

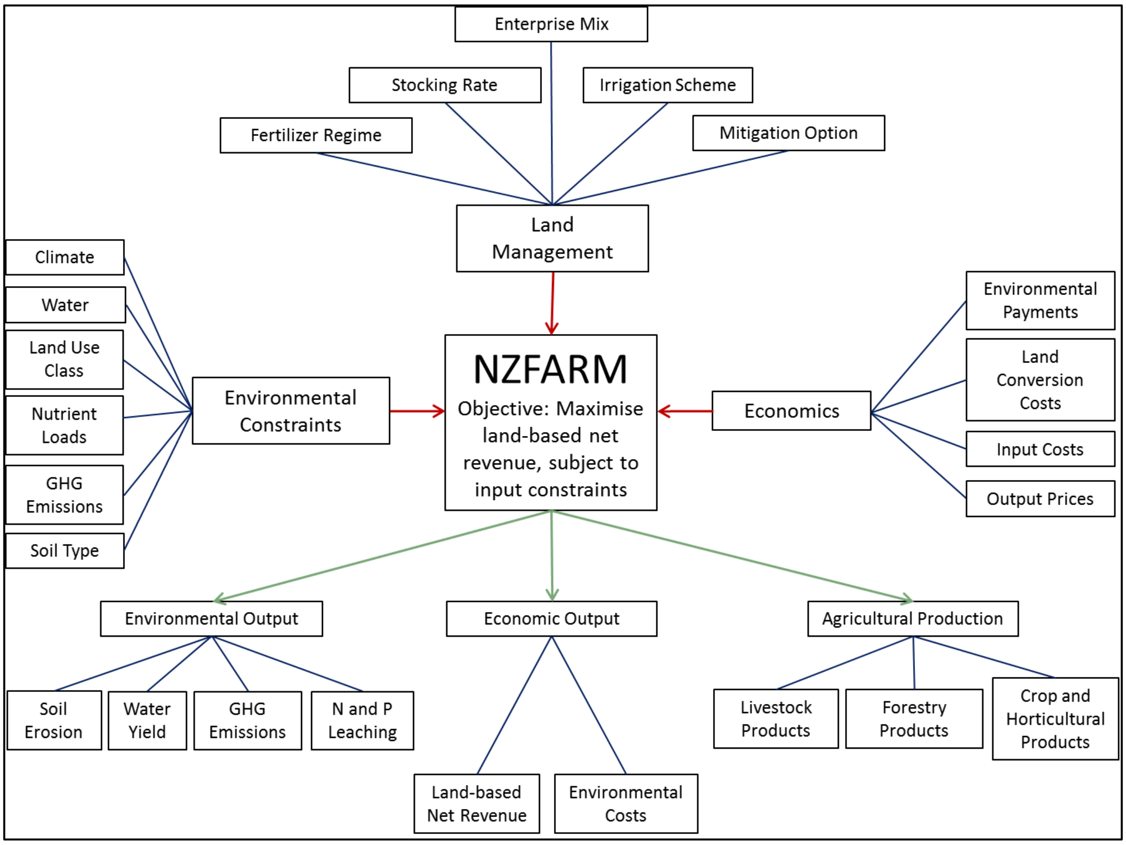
This report assesses the economic and environmental impacts of various water quality policies for the Hinds catchment in Canterbury. The analysis of the proposed policies for the case study is conducted using the New Zealand Forest and Agriculture Regional Model (NZFARM) a catchment-scale agri-environmental economic model. A more detailed description of the models is discussed below.

New Zealand Forest and Agriculture Regional Model (NZFARM)

The New Zealand Forest and Agriculture Regional Model (NZFARM) is a comparative-static, non-linear, partial equilibrium mathematical programming model of New Zealand land use operating at the catchment scale developed by Landcare Research (Daigneault et al., 2012a, 2012b; Greenhalgh et al., 2012). Its primary use is to provide decision-makers with information on the economic impacts of environmental policy as well as how a policy aimed at one environmental issue could affect other environmental factors. It can be used to assess how changes in technology, commodity supply or demand, resource constraints, or farm, resource, or environmental policy could affect a host of economic or environmental performance indicators that are important to decisions-makers and rural landowners. The model can track changes in land use, land management, agricultural production, N leaching, P loss and GHG emissions by imposing a variety of policy options that range from establishing a catchment-level cap and trade programme to imposing nutrient leaching constraints at the enterprise-level. The model is parameterised such that responses to policy are not instantaneous but instead assume a medium- to long-term response that landowners are likely to take over a 5–10-year period. A detailed schematic of the components of NZFARM is shown in Figure 5.

In addition to estimating economic output from the agriculture and forest sectors, NZFARM also tracks a series of environmental factors including N leaching, P loss and GHG emissions (carbon dioxide, methane and nitrous oxides). Simulating endogenous land management is an integral part of the model, which can differentiate between 'business as usual' (BAU) farm practices and less-typical options that can change levels of agricultural output, nutrient leaching, and GHG emissions, among other things. Key land management options include changing fertiliser regimes and stocking rates, adding an irrigation system or implementing mitigation technologies such as the installation of a dairy feed pad or the application of nitrogen inhibitors. Including a range of management options allows us to assess what levels of regulation might be needed to bring new technologies into general practice. Landowner responses to N leaching and P loss restrictions in NZFARM are parameterised using estimates from farm biophysical and budgeting models such as OVERSEER, SPASMO and FARMAX. Details on the specific land management, economic, and environmental factors tracked in this report are listed Appendix 1.

Figure 5: New Zealand Forest and Agriculture Regional Model (NZFARM)



The model's objective function is to determine the level of agricultural production that maximizes the net revenue[3] of production across the entire catchment area, subject to land use and land management options, agricultural production costs and output prices, and environmental factors such as soil type, water available for irrigation, and any regulated environmental outputs (eg, nutrient leaching limits) imposed on the catchment. Catchments can be disaggregated into sub-regions (ie, NZFARM zones) based on different criteria e.g. land use capability, irrigation schemes etc. such that all land in the same NZFARM zone will yield similar levels of productivity for a given enterprise and land management scheme. Total net revenue (π) in the catchment is specified in the model as:

$$Net\ Revenue\ (\pi) = \sum_{r,s,l,e,m} \begin{array}{c} Output\ price * Output\ quantity \\ + Other\ gross\ annual\ income \\ - Livestock\ cost * Livestock\ input \\ - Variable\ cost * Variable\ input \\ - Annualized\ fixed\ cost \\ - Tax * Environmental\ output \\ - Land\ conversion\ cost * area\ converted \end{array} \quad (1)$$

[3] Net revenue (farm profit) is measured as annual earnings before interest and taxes, or the net revenue earned from output sales less fixed and variable farm expenses. It also includes the additional capital costs of implementing new land management practices.

The objective function is mathematically specified as:

$$Max\ \pi = \sum_{r,s,l,e,m} \left\{ \begin{matrix} PQ_{r,s,l,e,m} + Y_{r,s,l,e,m} - \\ X_{r,s,l,e,m}\left[\omega^{live}_{r,s,l,e,m} + \omega^{vc}_{r,s,l,e,m} + \omega^{fc}_{r,s,l,e,m} + \tau\gamma^{env}_{r,s,l,e,m}\right] \\ -\omega^{land}_{r,s,l} Z_{r,s,l} \end{matrix} \right\} \qquad (2)$$

where P is the product output price, Q is the product output, Y is other gross income earned by landowners (e.g., grazing lease), X is the farm-based activity, ω^{live}, ω^{vc}, ω^{fc} are the respective livestock, variable, and fixed input costs, τ is an environmental tax (if applicable), γ^{env} is an environmental output coefficient, ω^{land} is a land-use conversion cost, and Z is the area of land-use change from the initial (baseline) allocation. Summing the revenue and costs of production across all NZFARM zones (r), soil types (s), land uses (l), enterprises (e), and management options (m) yields the total net revenue for the catchment.

The level of net revenue that can be obtained is limited not only by the output prices and costs of production, but by a number of production, land, technology and environmental constraints. Key land-management options tracked in the model include changing fertiliser regimes and stocking rates, adding an irrigation system or implementing mitigation technologies such as the installation of a dairy feed pad or the application of variable rate irrigation. More details on the specific land management, economic, and environmental factors tracked in the model are described below.

The production in the catchment is constrained by the product balance equation by a processing coefficient (α^{proc}) that specifies what can be produced by a given activity in a particular part of the catchment:

$$Q_{r,s,l,e,m} \leq \alpha^{proc}_{r,s,l,e,m} X_{r,s,l,e,m} \qquad (3)$$

Landowners are allocated a certain level of irrigation (γ^{water}) for their farming activities, provided that there is sufficient available water (W) available in the catchment:

$$\sum_{s,l,f,m} \gamma^{water}_{r,s,l,e,m} X_{r,s,l,e,m} \leq W_r \qquad (4)$$

Land use in the catchment is constrained by the amount of land available (L) on a particular soil type in a given NZFARM zone:

$$\sum_{e,m} X_{r,s,l,e,m} \leq L_{r,s,l} \qquad (5)$$

and landowners are constrained by the their initial land-use allocation (L^{init}) and the area of land that they can feasibly change:

$$L_{r,s,l} \leq L^{init}_{r,s,l} + Z_{r,s,l} \qquad (6)$$

The level of land use change in a given NZFARM zone is constrained to be the difference in the area of the initial land-based activity (X^{init}) and the new activity:

$$Z_{r,s,l} \leq \sum_{e,m}\left(X^{init}_{r,s,l,e,m} - X_{r,s,l,e,m}\right) \qquad (7)$$

and we assume that it is feasible for all managed land uses to change with the exception of native forestland and tussock.

$$L_{r,s,native} = L_{r,s,native}^{init} \quad (8)$$

In addition to estimating economic output from the agriculture and forest sectors, NZFARM also tracks a series of environmental factors including N leaching, P loss and GHG emissions. In the event that the central government or regional council regulates farm-based nutrient leaching or greenhouse gas emissions (γ^{env}) by placing a cap on a given environmental output from land-based activities (E), landowners could also face an environmental constraint:

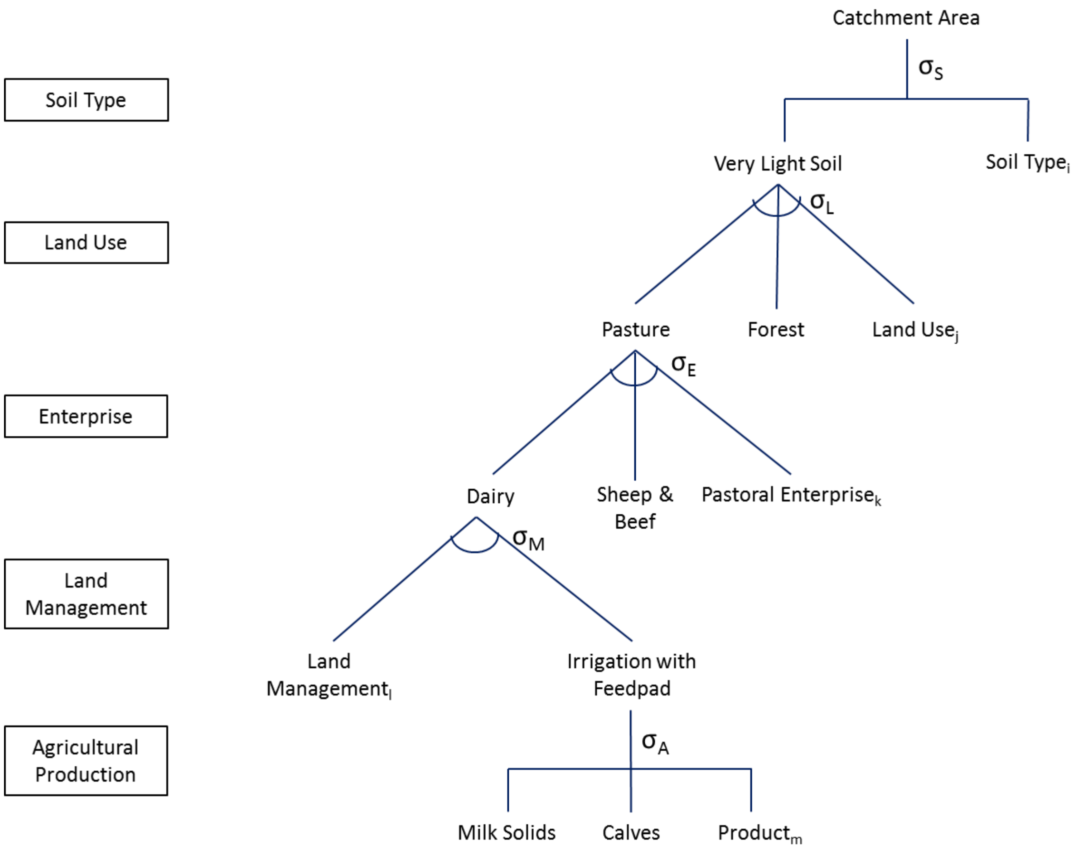
$$\sum_{s,l,f,m} \gamma_{r,s,l,e,m}^{env} X_{r,s,l,e,m} \leq E_r \quad (9)$$

Finally, the variables in the model are constrained to be greater or equal to zero such that landowners cannot feasibly use negative inputs such as land and fertiliser to produce negative levels of goods.

$$Y, X, L \geq 0 \quad (10)$$

The optimal distribution of soil type$_{1\ldots i}$, land use$_{1\ldots j}$, enterprise$_{1\ldots k}$ land management$_{1\ldots l}$, and agricultural output$_{1\ldots m}$ in a particular NZFARM zone are simultaneously determined in a nested framework that is calibrated based on the shares of current land use in the NZFARM zone. At the highest levels of the nest, land use is distributed over the NZFARM zone based on the fixed area of various soil types. Land use is then allocated between several enterprises such as arable crops (eg, process crops or small seeds), livestock (eg, dairy or sheep and beef), or forestry plantations that will yield the maximum net return. A set of land management options (eg, stocking rate, fertiliser regime, etc.) are then imposed on an enterprise which then determines the level of agricultural outputs produced in the final nest. Figure 6 shows the potential nest for an irrigated dairy farm in New Zealand that uses a feed pad and produces a series of outputs from pasture grown on very light soil.

Figure 6: An example of the structure of CET Function Nest in NZFARM.



The allocation of land to a specific soil type, land use, enterprise, land management, and product output is represented with constant elasticity of transformation functions (CET). The transformation function essentially specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of available options. The CET functions are calibrated using the share of total baseline area for each element of the nest and a parameter, σ_i, where $i \in \{s, l, e, m, a\}$ for the respective soil type, land use, enterprise, land management, and agricultural product output. CET parameters can theoretically range from 0 to infinity, where 0 indicates the input is fixed, while infinity indicates the inputs are perfect substitutes. The CET functions used in NZFARM are parameterized based on the estimates from existing literature of economic land use models (eg, Adams et al., 1996; Hendy and Kerr, 2006; Johansson et al., 2007; Kerr and Olssen, 2012; Li et al., 2012). The elasticities in the model ascend with each level of the nest between land use and land management, as there is typically more flexibility to transform the enterprise mix compared with altering the share of land use or to shift land use across soil types. The CET parameter for soil (σ_s) is set to be 0, as the amount of a particular soil type in a NZFARM zone is fixed. In addition, the parameter for agricultural production (σ_a) is also assumed to be 0, implying that a given activity produces a fixed set of outputs, as specified in equation 3.

A pivotal step to conducting policy scenarios in NZFARM is to calibrate the model baseline (no policy) scenario. NZFARM is calibrated such that optimality conditions are satisfied at observed levels of decision variables (eg, baseline land use and production matches input data). This is achieved using a methodology known as Positive Mathematical Programming (PMP) that has been proven to generate solutions with realistic diversification of production activities and smooth supply responses without adding weakly justified constraints to the model formulation (Howitt, 1995), such as placing ad hoc restrictions on how much land use can deviate from the baseline area. PMP has been used extensively to calibrate agri-environmental programming models in the US and Europe and thus is considered an appropriate methodology for calibrating NZFARM (Heckelei et al., 2012). NZFARM was used to model climate and water quality impacts in the Manawatu, Hurunui and Waiau catchments (Daigneault et al., 2012a, 2012b). More detail on PMP and the NZFARM framework are provided in Appendix 3.

NZFARM model is written and maintained in General Algebraic Modelling System (GAMS), and the baseline calibration and scenario analysis are derived using the non-linear programming (NLP) version of the COIN IPOPT solver (GAMS 2011).

Model Limitations

NZFARM was developed to assess impacts of policy on landowners. It does not account for all sectors of the economy. A tool such as NZFARM is typically developed to provide insight on the relative impacts and trade-offs across policy scenarios (eg, cap with various allocation) or price impacts (eg, different degrees of nutrient or GHG taxes), rather than for explicitly modelling the absolute impacts of a single policy scenario. NZFARM is used to compare consistently across policy options. Parameterisation of the model often relies on biophysical and economic input data from several different sources. Therefore, the estimated impacts produced by NZFARM should be used in conjunction with other decision support tools to evaluate the 'best' policy to manage nutrients. Details on some of the limitations of NZFARM include the following:

1. Calibration routine and model validation – The issue of model calibration is important when discussing the use of models to inform policy (environmental or otherwise), especially when the policy is still in the development stage and has not been implemented. In this situation we cannot always use empirical evidence to 'calibrate' or verify the model to ensure that it is correctly mimicking what may happen in reality (eg, nutrient limits are not yet common in New Zealand). Instead, we can 'test' the model to see if it responds in a logical and consistent manner to 'shocks' that have occurred in the past such as changes in commodity prices, the implementation of a forestry emissions trading scheme, the addition of new irrigation schemes, etc.
2. Input data – The quality and depth of the economic analysis depends on the datasets and estimates provided by biophysical models like OVERSEER and SPASMO, farm budgeting and production models such as FARMAX, and spatial datasets such as maps depicting current land use and sub-catchments or water management zones. Estimates derived from other data sources not included in this study may provide different results for the same catchment. Thus, analysis presented here should be used in conjunction with other information (eg, input from key stakeholders affected by policy, study of health and recreational benefits from water quality improvements) during any decision making process.
3. Representative farms – The model only includes data and management systems for representative farms for the relevant catchments. It does not explicitly model the economic impacts on a specific farm in the catchment, although it could do this if detailed data were available. As a result, some landowners in the catchment may actually face higher or lower costs than what are modelled using these representative farms.
4. Mitigation options – The model only includes management practices deemed feasible and likely to be implemented in a catchment as a result of nutrient reduction policies, given the current state of knowledge and technology available. It does not account for new and

innovative mitigation options that might be developed in the future as a result of incentives created under the policy. Although not all possible mitigation options may be included in the model, the suite of management practices will be large enough to account for a wide-range of costs (e.g., change in farm profit) and effectiveness (eg, change in nutrient leaching). Therefore, the average cost of the modelled policy should be within the range of what the actual average costs are likely to be as a result of the policy scenario analysed.

5. Optimisation routine – The model has the ability to track changes in farm revenue in 5–10-year time steps. NZFARM is structured such that the economic agents only respond to the 'state' of the world at any particular time step and are not able to foresee changes in environmental policy, market prices, or climatic conditions in the future. As farmers are not able to predict the future, the model replicates the situation that farmers are likely to face. As a result, the actual costs of the policy may be overstated.
6. Administration and transaction costs – NZFARM does not explicitly include administration and transaction costs of nutrient reduction policies in its optimisation routine. These include the upfront cost to landowners of developing a nutrient budget or hiring farm consultants and the cost for the regional council to allocate staff time and resources for administering the policy. Therefore, the overall costs of the policy that come directly from the model could be understated.
7. Regional economic impacts – NZFARM does not account for the broader impacts of changes in land use and land management beyond the farm gate. The flow-on effects from some of the policies investigated in this report could produce a significant change in regional employment and GDP. There could also be social and cultural impacts. The estimates produced by NZFARM provide just a subset of possible metrics that could be used to determine the 'best' policy to manage nutrients at the catchment-level. Analyses of regional economic impacts of nutrient reduction policies (e.g. Olubode-Awosola & Paragahawewa 2013) should be considered along with NZFARM estimates when determining the most appropriate policy for the Hinds catchment.

Data and Sources for Hinds Catchment

NZFARM accounts for all major land uses and enterprises in the Hinds catchment. Key enterprises include dairy, sheep, beef, and mixed arable. There are a total of 17 enterprises tracked in the model across the catchment. Enterprises included in the Hinds catchment modelling are shown in Table 3 and a more detailed description is listed in Appendix 1.

Table 3: Enterprises included in NZFARM for Hinds Catchment

Enterprise Name in NZFARM	Enterprise	Source
Dairy_1	Systems 5 Dairy – 4.2 cows/ha	MRB 2013
Dairy_2	Systems 4 Dairy – 3.7 cows/ha	MRB 2013
DairySup_1	Fully Irrigated Dairy Support	MRB 2013
DairySup_2	Partially Irrigated Dairy Support	MRB 2013
Arable_1	Process Crops – Fully Irrigated	MRB 2013
Arable_2	Small Seeds – Fully Irrigated	MRB 2013
Arable_2-3	Average of Arable_2 and Arable_3	MRB 2013
Arable_3	Livestock and Cereal – Partially Irrigated	MRB 2013
Arable_4	Livestock and Cereal – Dryland	MRB 2013
SNB_1	Dryland Sheep, Beef and Deer	MRB 2013
SNB_2	Partially Irrigated Sheep, Beef and Deer	MRB 2013
SNB_hill	Hill country Sheep, Beef and Deer	MRB 2013
Pigs	Outdoor Pigs	Lilburne et al. (2010)
Berryfruit	Berryfruit Irrigated	Lilburne et al. (2010)
Grapes	Viticulture Irrigated	Lilburne et al. (2010)
Pine	Exotic Forestry	Lilburne et al. (2010)
Native	Native Forestry	Lilburne et al. (2010)

* ‘SNB’ enterprises are referred to as sheep and beef in the report, and include deer

The current land use in the Hinds catchment (as of 2013) is shown in Figure 7. A land-use map based on Hill et al. (2012) was updated by MRB (2013) to match the current land-use distribution as of 2013. The catchment is approximately 139,000 ha in size and land use currently consists of 37% sheep and beef, 32% dairy, 20% arable, 8% dairy support, and 3% other land use (plantation forestry, native forestry, etc.).[4] It is estimated that about 85,000 ha of the catchment are under ‘irrigated’ dairy, sheep and beef, and arable enterprises, based on the enterprise categories used in the MRB (2013) report.[5] Proposals have been submitted to increase the irrigated area in the Hinds catchment by 30,000 ha through extensions to the Rangitata Diversion Race (RDR). This proposed change will likely result in changes in land use (primarily from sheep and beef to dairy and dairy support) and land management, and is included in the scenarios modelled for this study.

[4] Some dairy support grazing land is included in sheep and beef (MRB 2013).

[5] Enterprises are categorised either as irrigated, dryland or partly irrigated. We have categorised both irrigated and partly irrigated enterprises as irrigated enterprises in NZFARM. Thus the land area that is actually irrigated in the catchment may differ from the land area categorised as’ irrigated’ land in this study. We have accounted for different management systems for the key enterprises that may be irrigated or dryland (eg, sheep and beef or dairy support) based on the enterprise classification in the land-use map.

Figure 7: Current Land Use in Hinds Catchment

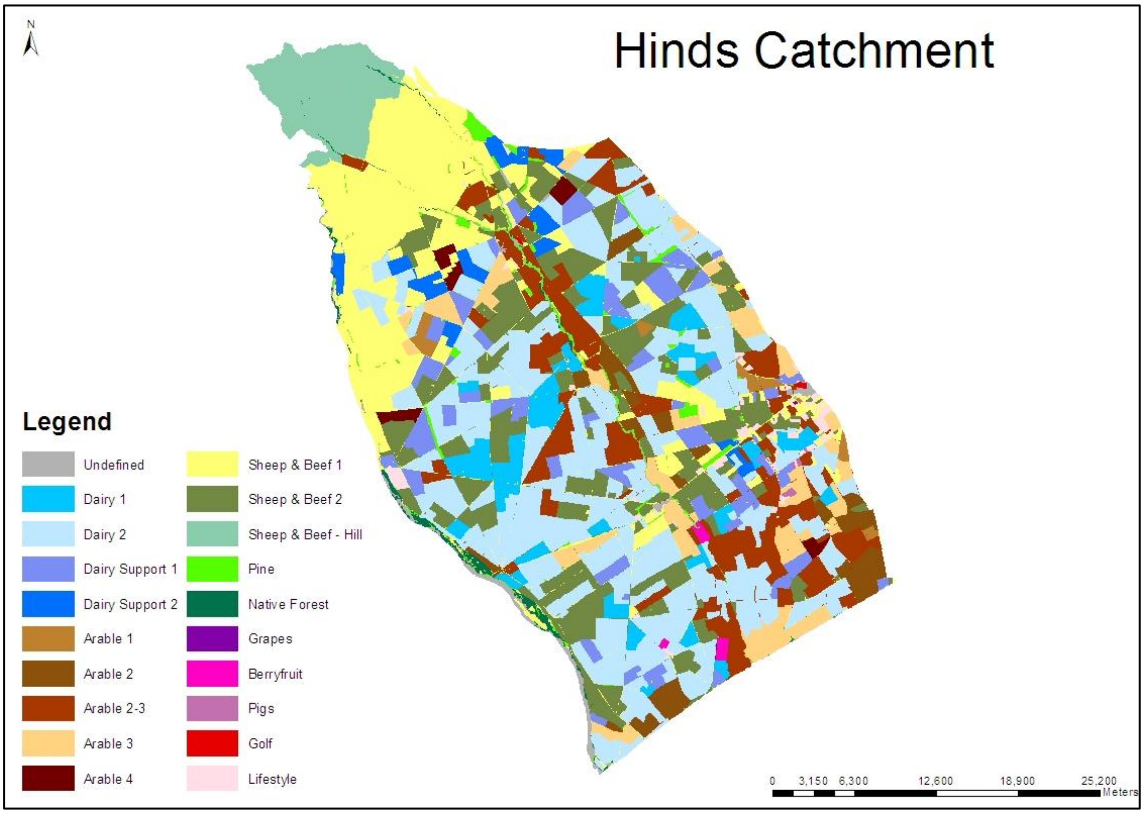
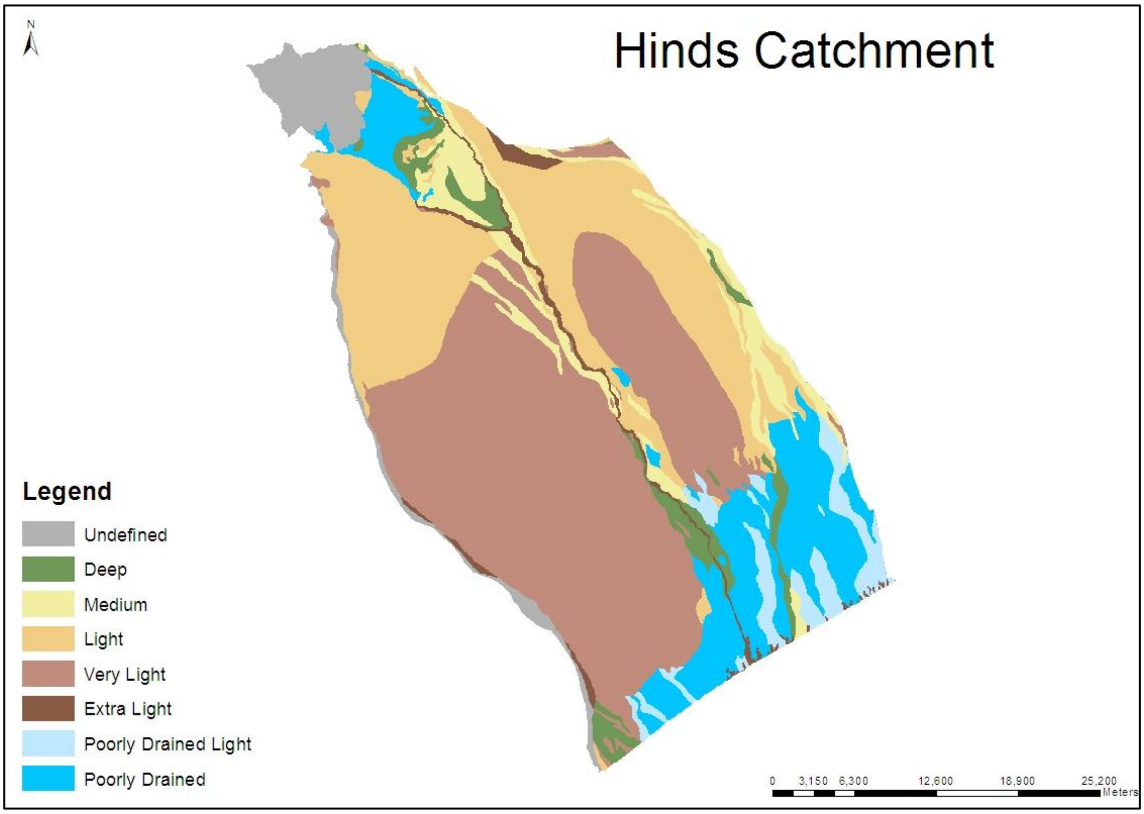


Figure 8 shows the distribution of soils in the catchment. Soils are categorised based on drainage and profile available water (Lilburne et al. 2010). Soil type is an important determinant of N leaching rates in the catchment.

Figure 8: Distribution of Soil Drainage Categories in the Hinds Catchment



Each enterprise requires a series of inputs to maximize production yields, given input costs and output prices. The cost of inputs coupled with water and input constraints can limit the level of output from a given enterprise. Enterprises also face fixed and variable costs ranging from stock replacement costs to depreciation. Costs for each enterprise varied across the catchment. Altering input costs or output prices, as well as the list of enterprises available for a given NZFARM zone, change the distribution of enterprises (and their area) but total land area remains unchanged across all modelled scenarios.

The production yields, input costs (fixed and variable), and output prices for pastoral, arable, and viticulture enterprises were provided by McFarlane Rural Business Ltd (MRB, 2013). Forestry yields were obtained from Kirschbaum and Watt (2011) with timber and pulp prices obtained from Ministry of Agriculture and Forestry (MAF, 2010). Pigs and berryfruit farm budgets were obtained from estimates used for the Hurunui and Waiau catchment parameterisation of NZFARM (Daigneault et al., 2012a).

N leaching and P loss rates for all pastoral and arable enterprises as well as grapes were estimated by McFarlane Rural Business Ltd using OVERSEER (version 6) to match the soil and productivity conditions in the catchment (MRB 2013). The estimates for N leaching from pigs, pine plantations, native vegetation, and berryfruit were taken from Lilburne et al. (2010). The baseline N leaching estimates are listed in Table 41 of Appendix 1.

GHG emissions for most enterprises were derived using the same methodology as the New Zealand GHG Inventory (NZI), which follows the IPCC’s Good Practice Guidance (2000). Pastoral emissions were calculated using the same emissions factors as the NZI, but applied to per hectare stocking rates specific to the catchment. Forest carbon sequestration rates were derived from regional lookup tables (Paul et al., 2008). All emission outputs are listed in tonnes per carbon dioxide equivalent (CO_2e). To be consistent with the NZI (MfE, 2011), all emissions were converted to CO_2e using the 100 year global warming potentials of 21 for methane (CH_4) and 310 for nitrous oxide (N_2O).

A summary of data sources for the key inputs in NZFARM is listed in Table 4.

Table 4: Summary of Key data sources for NZFARM parameterisation of Hinds Catchment

Data	Source
Land use	MRB (2013), Hill et al. (2012), ECan (2013a)
Soil type	Lilburne et al. (2010)
Farm budgets	MRB (2013), Daigneault et a.l (2012a)
Farm production	MRB (2013), Daigneault et a.l (2012a)
N leaching	MRB (2013), Lilburne et al. (2010), Kirschbaum and Watt (2011)
P loss	MRB (2013)
GHG emissions	MRB (2013), Paul et al. (2008), MfE (2011)

Land management options tracked in the model are listed in Table 5 and explicitly based on data from MRB (2013), with input from ECan. The mitigation options were established as bundles of practices that would be implemented together over a reasonable time frame. These are organised as current, good, and advanced mitigation (AM) management practices that are categorised as follows:

- Current (Base) Practice: The average (representative) farm in the catchment as of June 2012.
- Good Management Practice (GMP): Practices that are generally undertaken by the top 50% of farmers as of June 2012. These practices typically reflect farmer compliance with supplier and local government regulations.
- Advanced Mitigation 1 (AM1): Practices that modify farm systems to employ some simple nutrient loss reduction strategies. These changes are expected to have minimal effect on net farm revenue but will require some management alterations and capital purchases to upgrade existing infrastructure. Also includes practices in GMP.
- Advanced Mitigation 2 (AM2): Practices that significantly modify farm systems to reduce nutrient losses, primarily through capital investment. These changes are not expected to impact production, but additional capital costs could reduce net farm revenue. Also includes practices in GMP and AM1.
- Advanced Mitigation 3 (AM3): Practices requiring major systems change to reduce nutrient losses. These include reducing physical inputs and stocking rates beyond economically optimal levels. These changes are expected to reduce net farm revenue. Also includes practices in GMP, AM1, and AM2.

The mitigation options listed in the 'good management practice' bundle specified by MRB is limited. The general consensus on good management practices' may differ from what is defined by MRB. For this report, GMPs can be considered 'industry or consent compliant' practices.

Table 5: Summary of the modelled land management options (MRB 2013)

Management Practice Bundle	Description and Management Options
Current (Base) Practices	• Typical farming practises in the catchment in the absence of water quality management policy.
Good Management Practices *	• Reduction in fertiliser in crops following large winter depositions of nitrogen. • Dairy to install 30+ days' effluent storage and greater reduction in N use on effluent applied land.
Advanced Mitigation Level 1 Practices (Management changes)	• Installation of soil moisture monitoring gear and VRI on existing centre pivots. • No urea applications in May. • Adjust cropping fertiliser rates and types to best suit plant requirements and timings. • Use of yield maps to define an assumed 10% of the paddock which only yields half of the paddock average. • Use variable rate fertiliser technology. • Limit each urea application to <140kg/ha. • Variable Rate Fertiliser. • Gibberellic Acid to substitute some Spring and Autumn Nitrogen on Pastures. • DCD (Dicyandiamide) Use combined with nitrogen based fertiliser reductions to match. • Mixed Pasture Sward. • Short Rotation Ryegrass and White Clover Pasture. • Modify existing centre pivot irrigators to Variable Rate Irrigation technology on 90% of area. • Optimise stocking rates.
Advanced Mitigation Level 2 Practices (Capital investment)	• Modify 90% of irrigated area to include centre pivots/laterals fitted with Variable Rate Irrigation technology. • Employ Normalised Difference in Vegetative Index (NDVI) sensing technology and consequent Variable Rate application of liquid urea. • Dairy farms to install covered feed pads and required effluent systems.
Advanced Mitigation Level 3 Practices (System change)	• Reduce nitrogen fertiliser applications by 15% and model appropriate reductions in production. • Reduce stocking rates by 10% (without increasing production to compensate). • All cows wintered in barns and dairy farms grow sufficient winter feed (fodder. beet to lift). • No winter feed crop yields over 14t/ha.

* Good management practises generally reflect what the top 50% of farmers are doing as of June 2012. These practices typically reflect farmer compliance with supplier regulations and local government law.

Land management options were modelled only for pastoral and arable enterprises for this report. The per hectare estimates of these land management options for farm net revenue and cash farm surplus relative to the impact in N leaching as estimated by MRB (2013) are shown in Figure 9 and Figure 10, respectively. Table 42 and Table 43 in the Appendix present more details on the impacts of the land management options. Figure 11 shows for each enterprise the relative impact of the various land management options compared to the baseline. For example, for ‘dairy 1’ adopting the AM1 land management option results in a slight increase in net farm revenue and cash farm surplus compared to the baseline, while N leaching is reduced by about half compared to the baseline.

Figure 9: N leaching v. Net Farm Revenue for Land management options

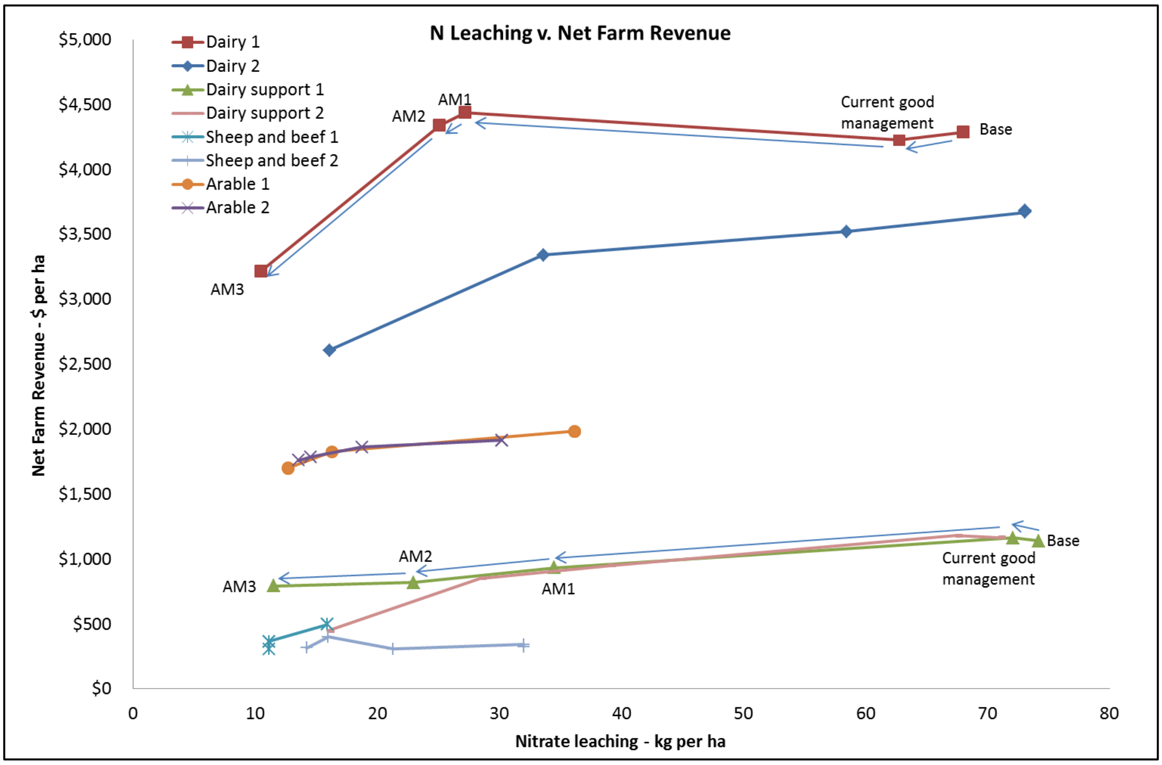


Figure 10: N Leaching v. Cash Farm Surplus for land management options

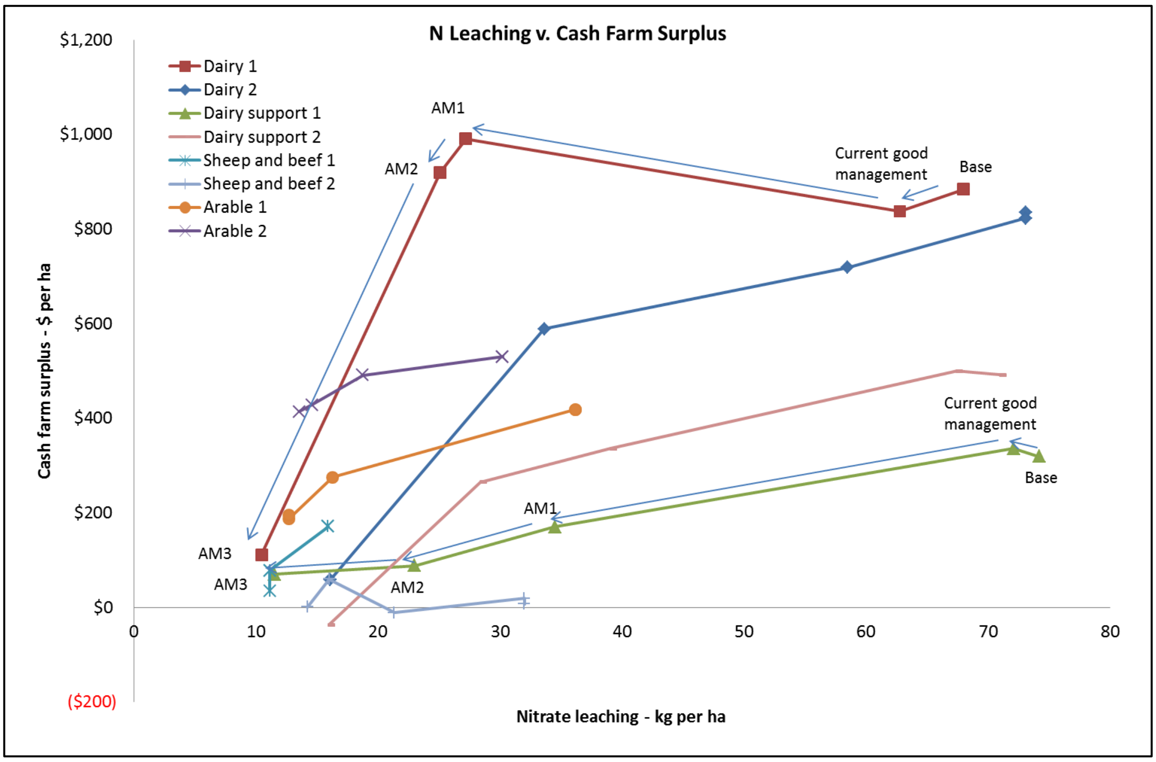
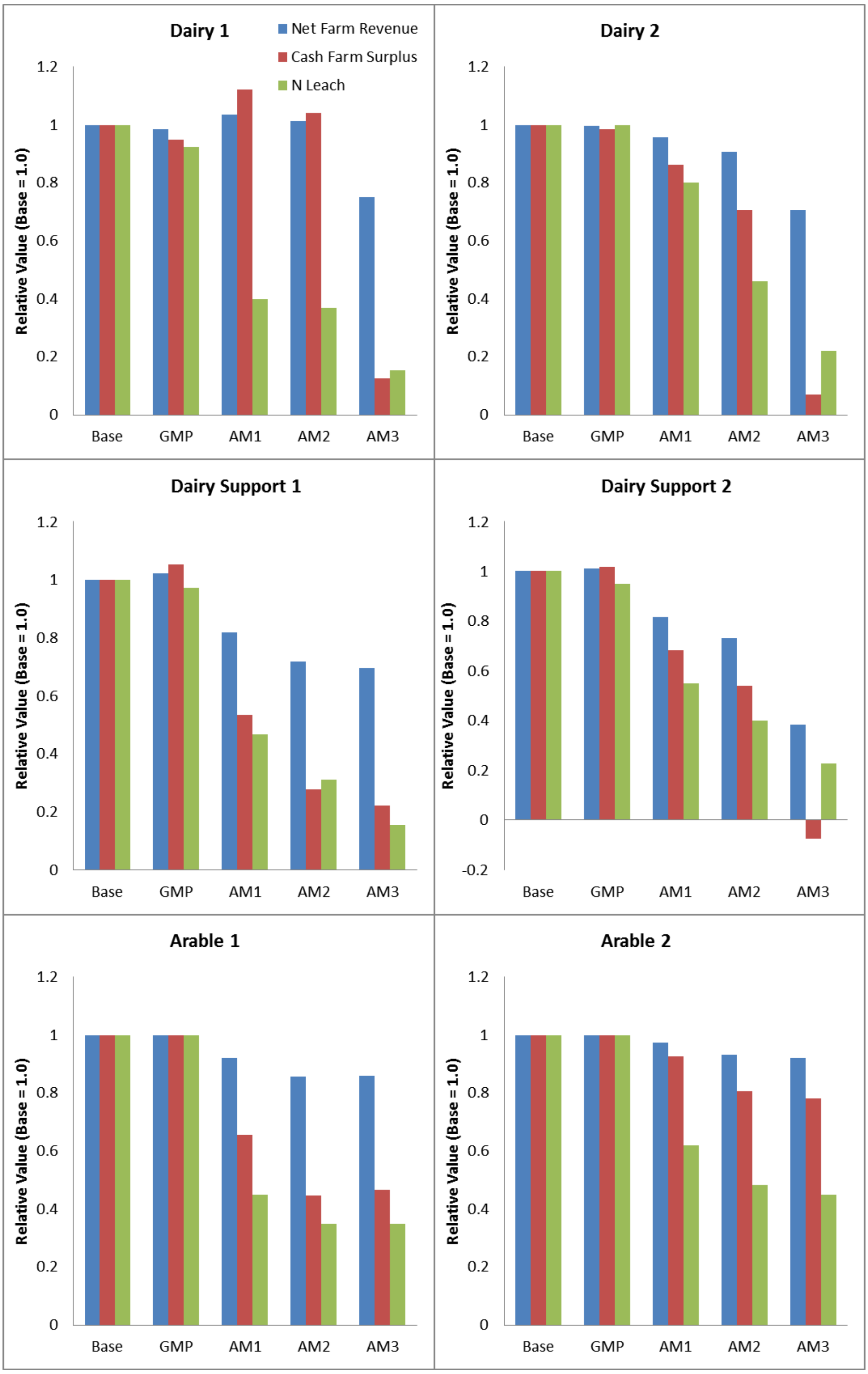
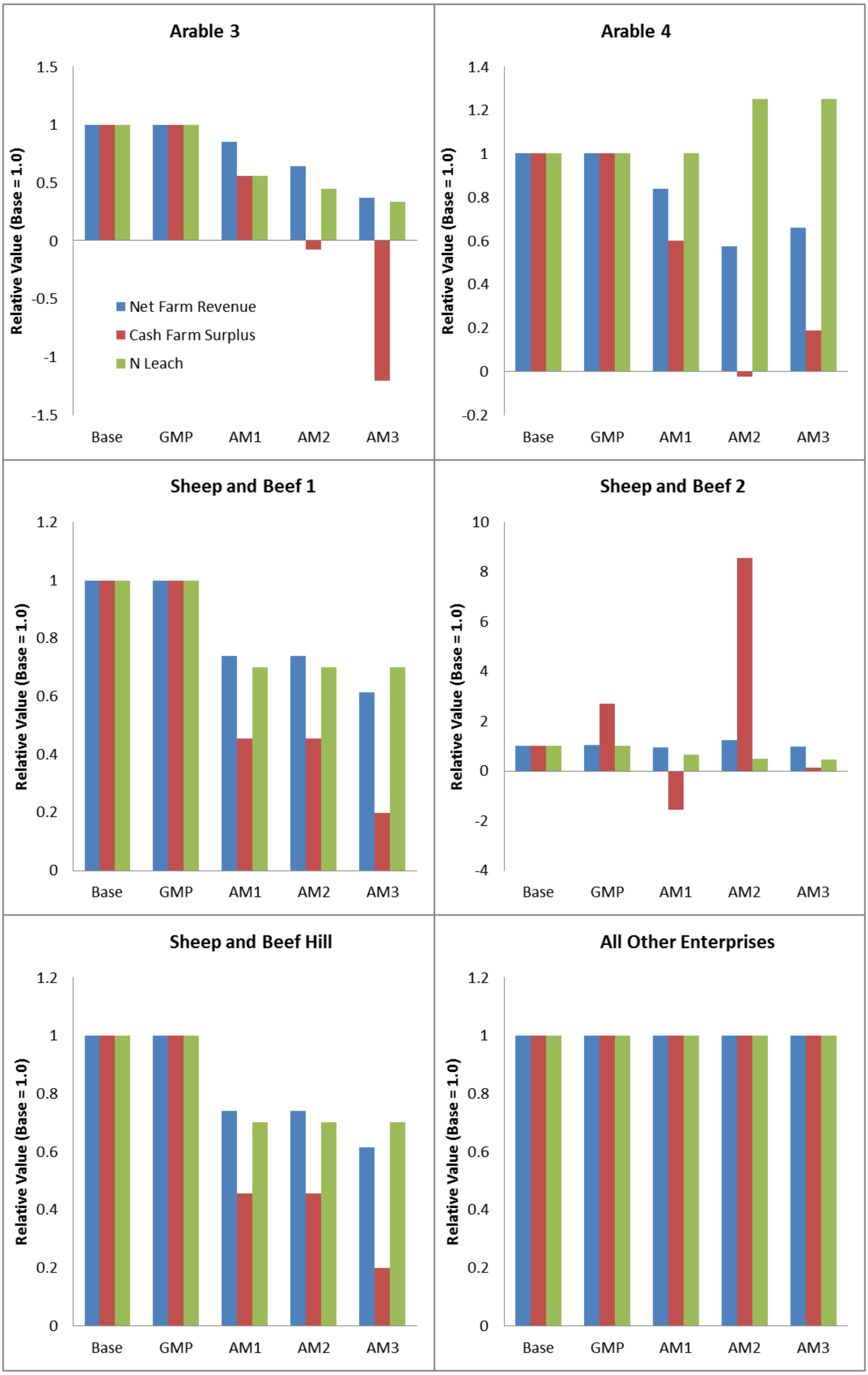


Figure 11: Impact of land management options, by enterprise




Arable 3
Arable 4
Sheep and Beef 1
Sheep and Beef 2
Sheep and Beef Hill
All Other Enterprises
Relative Value (Base = 1.0)
Net Farm Revenue
Cash Farm Surplus
N Leach
Base
GMP
AM1
AM2
AM3

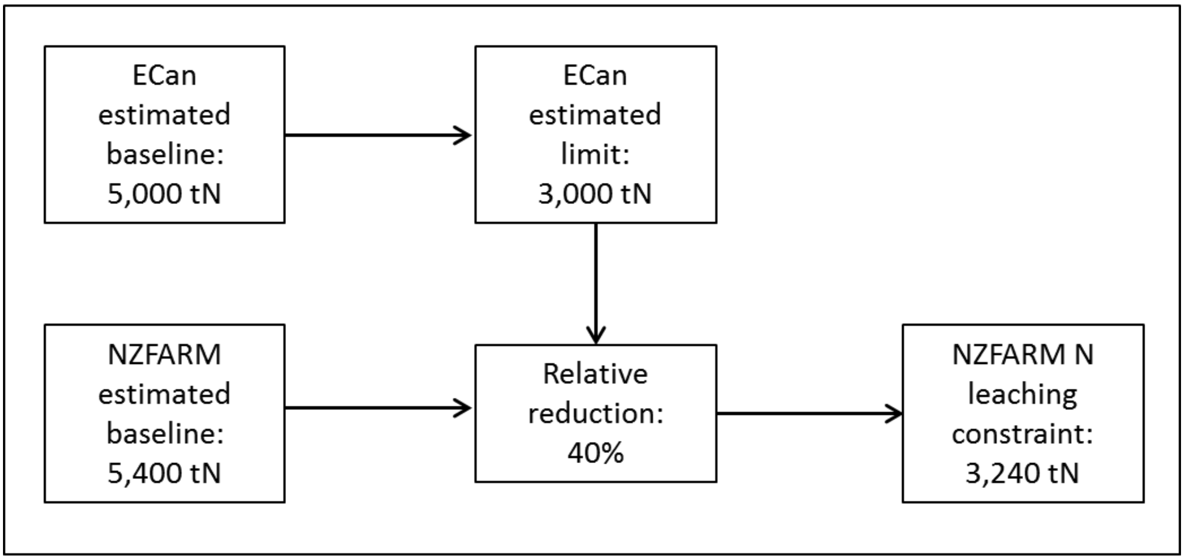
Modelling Nutrient Reductions Targets in NZFARM

The analysis of nutrient reduction policy scenarios are based on the catchment N limits being set by a community collaborative process, overseen by the Hinds Zone Committee. The factors that are involved in setting load limits and linking point diffuse sources to these limits are complex and beyond the scope of this study. It is possible that the limits used in this report will be different from the final set of limits established by the Zone Committee.

The proposed limits are imposed in most of the NZFARM scenarios as a binding limit that is defined as an environmental constraint in NZFARM (see equation 9). That is, the model is programmed so that it will optimise net revenue in the catchment subject to meeting the defined N leaching constraint, given the distribution of baseline land use and available mitigation options.

The land-use categories, farm budgets, N leaching data and assumptions used by ECan to establish the baseline N leaching total and reduction targets can sometimes vary from the data and assumptions used to parameterise and produce baseline N leaching estimates in NZFARM. As a result, the total N load estimated using the two approaches may vary. We set the N leaching constraint in NZFARM by using the relative difference between the ECan baseline N leaching total and the proposed N limit. A simple example of the logic used to translate a 40% reduction target in NZFARM using the values estimated by ECan is shown in Figure 12.

Figure 12: An example to illustrate how the relative differences in Environment Canterbury (ECan) N limit to adjust NZFARM catchment limits



Other details on specific assumptions that were made, such that policies can be related back to the ECan limits, are included below.

3 Nutrient Reduction Policies

All the nutrient reduction policy scenarios to improve water quality investigated in this report were defined by ECan and MfE, and analysed using NZFARM model. We assess the economic incentives to reduce nutrient output at least cost to the landowner. Core policies include (1) promoting the adoption of improved land management practices, (2) requiring individual landowners to meet specific maximum N leaching targets, (3) setting a catchment-wide cap and allocating nutrient discharge allowances (NDAs) that landowners are able to trade between each other, and (4) a hybrid of these approaches.

Most policy scenarios were analysed based on the nutrient reduction targets currently being considered by the Hinds Zone Committee. For the scenario that looks at a specific farm management practice, we assess how large the potential change in total nutrient leaching could be, given that all landowners in the catchment eventually are required to adopt a given practice.

We discuss the general structure for each policy scenario and why they are considered for protecting or improving water quality. A summary of the key features, advantages, and disadvantages of these scenarios is listed in Table 6. The results of these policy scenario analyses are presented in Chapter 5.

Improving land management practices

One approach to managing nutrient losses is to promote the adoption of improved land management practices. In this case, mitigation is carried out through a combination of specific on-farm mitigation methods. The adoption of management practices can be done through regulatory (eg, mandate fencing of streams) or industry-backed measures (eg, Dairying and Clean Streams Accord).

While perceived to be relatively easy to administer, a challenge with the practice-based policy approach is that while it may be effective at getting practice change it may not achieve the desired environmental outcome. Tracking practice uptake and not the reduction in N leaching as a result of these practices changes could mean that total N leaching increases as landowners continue to intensify their production (eg, by changing land use or increasing stocking rates) even when they are adopting improved land management practices.

Land management practises (eg, current, AM1, etc.) modelled in this report are defined by MRB (2013) and highlighted in Table 5. For most policies scenarios in this report we do not explicitly model the impact of adopting management practices as a stand-alone option. However, these practices are a viable mitigation option in policy scenarios that cap N leaching and/or allow trading. Thus, some landowners may adopt a particular mitigation bundle if it is estimated to be a cost-effective option to meet a nutrient reduction target.

The policy scenario included in this report to assess the potential impact of promoting the uptake of improved land management practices assumes that all pastoral and arable farmers[6] in the catchment adopt AM1 practices. We modelled the AM1 scenario because these practices are estimated to reduce nutrient losses significantly relative to the baseline with a minimal effect on

[6] No mitigation options are modelled for horticulture, pig and forestry enterprises. ECan may intend to require all landowners to adopt AM1 practices, but this option is out of the scope of this report.

net farm revenue. As described above, AM1 practices will require some management alterations and capital purchases to upgrade existing infrastructure. It is also assumed that farmers would implement the entire bundle of AM1 practices over a reasonable timeframe.

Farm-specific caps on nutrient leaching

The following subset of policy scenarios assumes that individuals cannot leach more than a specified maximum amount of nutrients (kgN/yr) from their land (ie, a nutrient discharge allowance or NDA). Maximum leaching rates can be the same across all enterprises and land characteristics (eg, average), or they can vary by a metric, such as land capability class (eg, natural capital approach). Allocating farm-specific caps requires the benchmarking of all farms in the catchment to determine whether they are above or below the allowances they were allocated, and thus could be more costly to administer than the improved land management practice approach.

For these scenarios, it is assumed that landowners are not allowed to trade their allowances with anyone else in the catchment. This makes the policy easier from an administrative standpoint, but could result in a greater cost to farmers who might have to undertake significant changes in management or land use to meet the target. It could also result in reducing total nutrient leaching beyond the catchment target because some landowners will already be under the mandated limit in the absence of the policy and therefore have an excess allowance that is unused.

Average Allocation Approach

Under an average allocation scenario, all landowners in the catchment are given the same nutrient discharge allowance (eg, 15 kgN/ha/yr). The allocation of the resource would be achieved by dividing the target catchment load by the total productive area in the catchment. This approach is simple, and treats all landowners the same regardless of their land characteristics. As a result, many landowners may have to change their land use or management to meet the given nutrient leaching requirements. Average allocation is likely to set an upper limit on the cost of the nutrient policy scenarios as there is limited landowner flexibility to meet the catchment nutrient target.

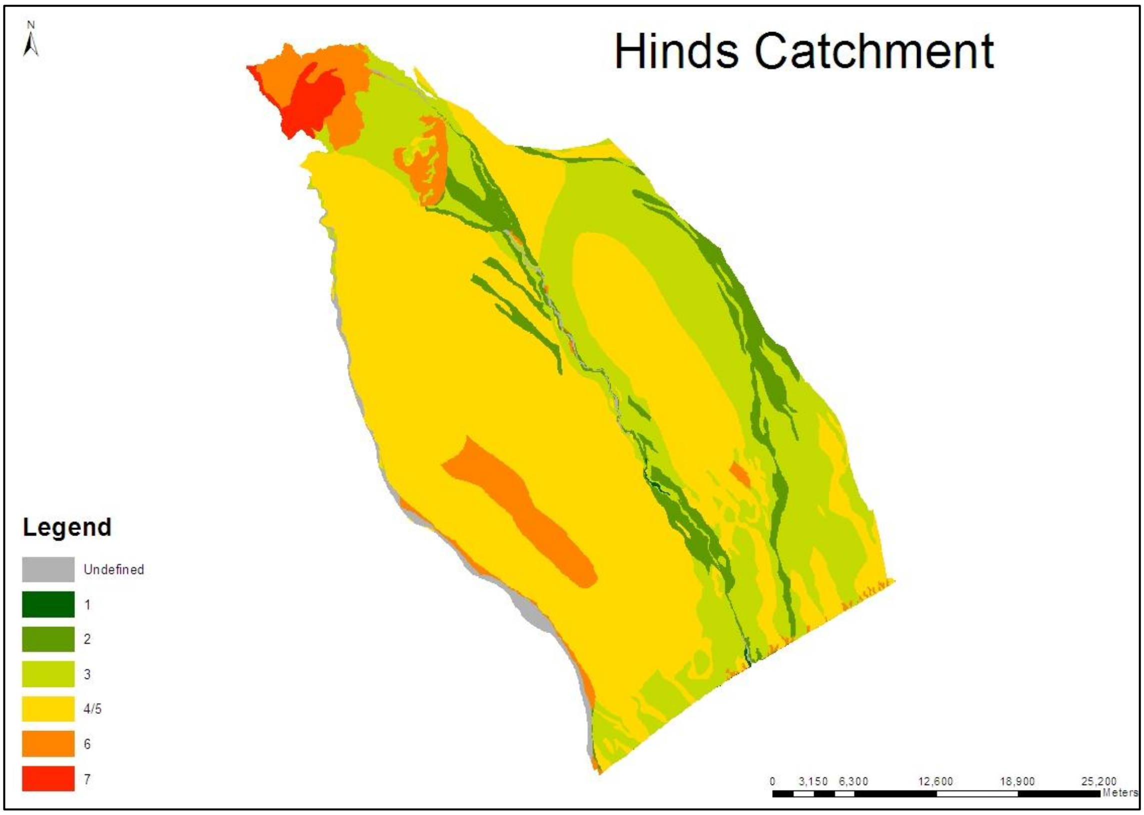
Natural Capital Approach

Under the natural capital approach nutrient discharge allowances are based on the physical characteristics of the land or the soil type. This typically reflects either the land's productive potential or vulnerability to nutrient leaching, and is independent of existing land use.

The approach supports the sustainable use of both land and water resources by favouring land areas that have good productive potential. Horizons Regional Council's most recent version of the One Plan proposes to set cumulative nitrogen leaching rates (kgN/ha) based on the productivity potential of eight land use capability classes (LUC). We have modelled a similar approach, but modified to 'fit' the Canterbury region (Lilburne et al. 2013). One difference between the Horizon's approach and the approach modelled here is that this analysis assumes an attenuation rate of 1.0, while the Horizons LUC rates were developed using an attenuation rate of 0.5 (Clothier et al., 2007).

For this allocation scenario Hinds catchment is divided in to seven NZFARM zones based on the land use capability (LUC) classes (Figure 13) as derived from S-map[7] and the Land Resource Inventory[8] (Lynn and Lilburne, 2013). The estimated N allowance for each LUC class in the catchment is specified in Chapter 5.

Figure 13: NZFARM zones based on the Land Use Capability (LUC) classes derived from S-map and the LRI



Nutrient cap and trade policies

A cap and trade or trading programme is a market based approach that often considered for reducing nutrients in a catchment because they are typically more flexible and cost effective than requiring all landowners meet individual targets or implement certain land management practices (i.e. command and control). This approach provides some degree of environmental certainty for the regulatory agency as it sets the nutrient cap or target that must be achieved; thereby ensuring landowners adapt their land use or land management to meet the target. This option has been proposed for reducing nutrient, and is currently operational in the Lake Taupo catchment (Environment Waikato 2009).

[7] http://smap.landcaresearch.co.nz

[8] http://lris.scinfo.org.nz

Nutrient trading markets have a limit (or cap) on the total annual nutrient leaching in a catchment that will achieve a specified environmental goal. This cap is then allocated between the relevant nutrient sources (eg, farmers) in the catchment, often as nutrient discharge allowances. Sources are then required to hold sufficient allowances to cover their total nutrient losses (or discharge), and to provide a reconciliation at the end of a fixed term. Those sources that do not hold enough allowances to cover their discharges must either reduce their discharges or buy additional allowances from other participants who have surplus allowances.

Nutrient trading markets are attractive for a number of reasons. Sources have flexibility with their discharge level: they can increase, maintain, or decrease their discharge, as long as they hold sufficient allowance to cover their N leaching. They also have flexibility in how they mitigate their nutrient losses, including land-use change. This flexibility encourages profit maximizing landowners to mitigate their reduction as long as their mitigation costs are less than the market price of an allowance; those with lower mitigation costs will mitigate and profit by selling some of their allowance to those with higher mitigation costs. Theoretically, this will equalize marginal mitigation costs around the catchment and ensure that that mitigation is carried out by those who can do so most cheaply.

The costs of establishing a nutrient trading programme include the setting of the regulation and benchmarking farms to determine whether they are above or below the allowances they were allocated (farm-specific caps with no trading would face the same costs) as well as an additional cost around the trading component of the programme. There are both direct and indirect costs for the trading component. Direct costs include any one-time market establishment cost (eg, development of a market place) and then any on-going allowance transfer costs (eg, costs to charge the conditions on consents). The costs associated with the regulatory component include setting the catchment cap, allocating the cap between sources and establishing the baseline or benchmark nutrient losses for each source and issuing consents that outline the nutrient discharge allowance (NDA) for each source. We model a series of possible allocation approaches and estimate the potential cost to the landowners and the community of each approach. Note that the average and natural capital allocation approaches above could also be used as a part of a cap and trade scenario but these have not been modelled.

“Grandparenting” allocation, catchment-wide cap and trade programme

Under a “grandparenting” approach each source is allocated an allowance based on their existing (or reference year) nutrient discharge. For the agricultural sector, this allocation approach often allows existing land uses to continue at the owner’s discretion, but only within a farm’s total discharge allowance. If farmers wish to increase their land-use intensity beyond the grandparented level, they must acquire NDAs from other landowners in the regulated area to meet the cumulative nutrient leaching targets for the catchment. Some landowners might find it more advantageous (ie, profitable) to reduce their nutrient losses through land management and sell excess allowances to others.

For this study, all landowner were allocated NDAs based on a reference (baseline) year enterprise mix and nutrient loss less the required percentage change in N relative to the no policy baseline scenario. Landowners were also allowed to trade their NDAs between others in all areas of the catchment.

Nutrient Vulnerability Allocation Approach

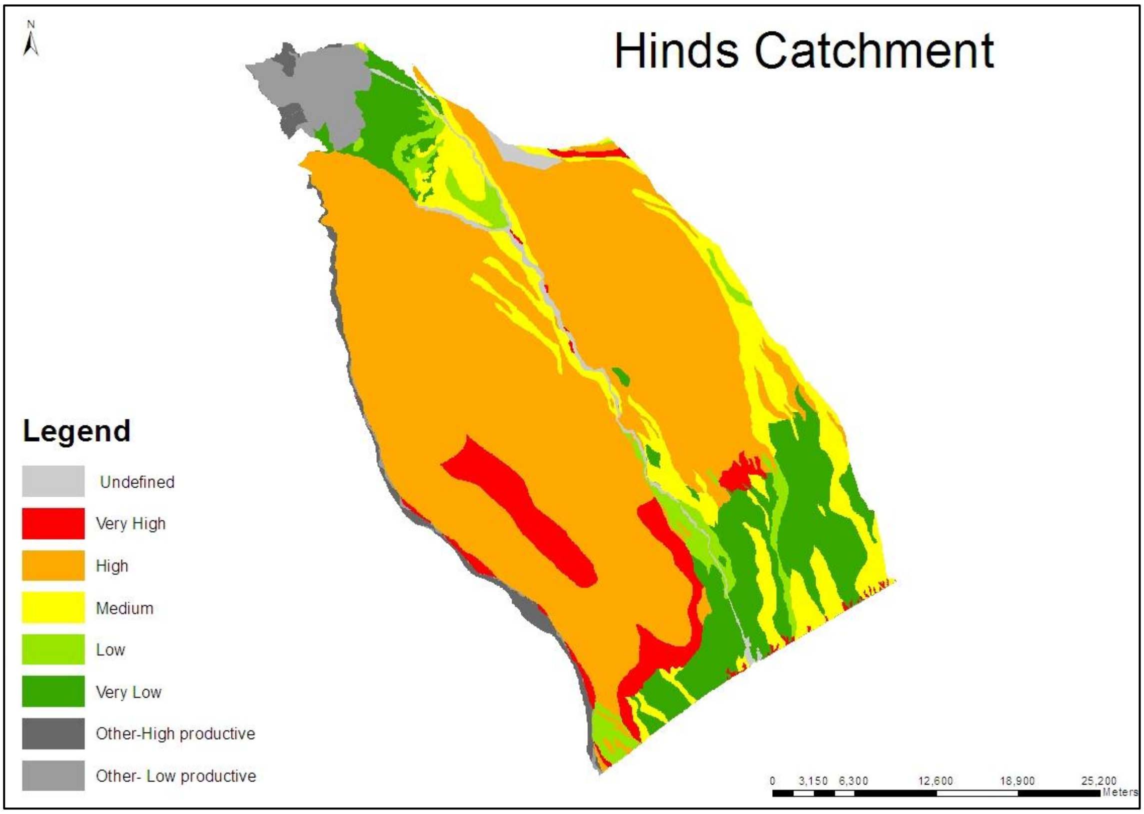
The nutrient vulnerability allocation approach allocates nitrogen discharge allowances according to the level of filtering service provided by the different soils. Webb et al. (2010) describe a simple model for nitrate leaching vulnerability for Canterbury soils. Soils with very high vulnerability reflect the soils poor capacity for filtering nitrogen, and soils with low vulnerability indicate soils with relatively high filtering capacity. This relative capacity is quantified by normalising modelled leaching results from Overseer (the very vulnerable soils have 30% of the filtering capacity of the least vulnerable soils).

This vulnerability-based allocation method comprises two steps. The first is to assign an initial allowance sufficient to allow a land owner to run a dryland sheep and beef farm system. In most catchments the cumulative load from 100% dryland sheep and beef farms will be less than the catchment's target load. When this is the case, the difference in the load is then redistributed in a second step according to the level of filtering service provided by the soil. Soils with a high filtering capacity are allocated more of the remaining load (proportional to their filtering capacity), thereby encouraging intensification on the least leaky soils. Soils with poor filtering capability are allocated a smaller portion of the remaining load potentially limiting the intensification of these leakier soils. Land that has severe limitations to intensive agricultural production (eg, too steep) is not given any additional load.

The final NDA is the sum of the initial NDA value and the amount allocated in the second step (if any). This allocation approach means all land owners including those with the leakiest soils will still be able to farm (dryland sheep and beef) – but may not be able to intensify to other land uses, and intensification is encouraged on the less leaky soils.

For this scenario, NZFARM zones in the Hinds catchment are defined based on the five N leaching vulnerability classes (Figure 14). Where N leaching vulnerability is not classified (due to missing soil data) it is defined as either high productive or low productive land based on the NMZs described in the earlier section. The estimated N allowance for each nutrient vulnerability class in the catchment is specified in Chapter 5.

Figure 14: NZFARM Zones based on the Nutrient Vulnerability Classes.



Auction Nutrient Discharge Allowances

An auction-based allowance requires that all farmers must purchase an allowance for every unit of nutrient they discharge above a benchmark level considered unmanageable or cannot be mitigated. Allowances end up in the hands of those who value them the most through an auction where farmers will theoretically bid up to their marginal cost of mitigation for an allowance. Because there is no free allocation, a high NDA price could result in a relatively large transfer of money from the landowner to the council. This revenue can be spent in any way the council sees fit, such as reducing rates, paying for additional mitigation, or investing in infrastructure. It could also be returned to land owners to help offset the cost of purchasing NDAs and carrying out the mitigation required to achieve the nitrogen reduction goal.

In this analysis, we assume that there is zero free allocation and thus farmers must acquire NDAs for every kgN leached from their land. For this report we also assume that the money is collected by the council but do not make any decision on how the revenue is used. As there is zero free allocation, the policy scenario estimates will represent an upper bound of the cost of this allocation approach.

Hybrid Policy Approaches

This report also assesses the impact of three ‘hybrid’ scenarios that combine a mix of cap and trade, farm-specific caps, and resource rental charges (ie, nutrient discharge tax). These scenarios are considered because they have the possibility to reduce the administrative burden by limiting the scope of the trading programme or by creating a source of income to administer any nutrient policy imposed for the council through a resource rental charge.

Grandparenting allocation, catchment-wide cap and trade programme plus a resource rental charge

This scenario is similar to the grandparenting allocation with catchment-wide cap and trade programme, but with the addition of a resource rental charge. Under this scenario with a resource rental charge, each landowner is allocated a nutrient discharge allowance based on a percentage reduction from their reference year leaching rates. The trading programme allows NDAs to be traded between farmers in all areas of the catchment. The key addition to the standard grandparenting cap and trade scenario is that the council also imposes a resource rental charge (eg, $2.50/kgN) on all N leached in the catchment. For example, if a dairy farmer has is allocated 30 kgN/ha under this policy scenario, he must both have the necessary level of NDAs as well as pay a rental fee for all 30 kgN/ha. Resource rental charges are a way of ‘internalising’ the cost of nutrient losses from farms. In this instance, this charge would not fully internalise the costs. It is, instead, intended to assist the Regional Council in raising funds to administer the nutrient reduction policy and possibly implement larger mitigation projects in the catchment that are beyond the ability of a single landowner. It may also provide another incentive for landowners to reduce their total N leaching in the catchment because in addition to needing to meet the allocation requirement, they also face this rental charge on N losses from their farm.

Equal Allocation Approach

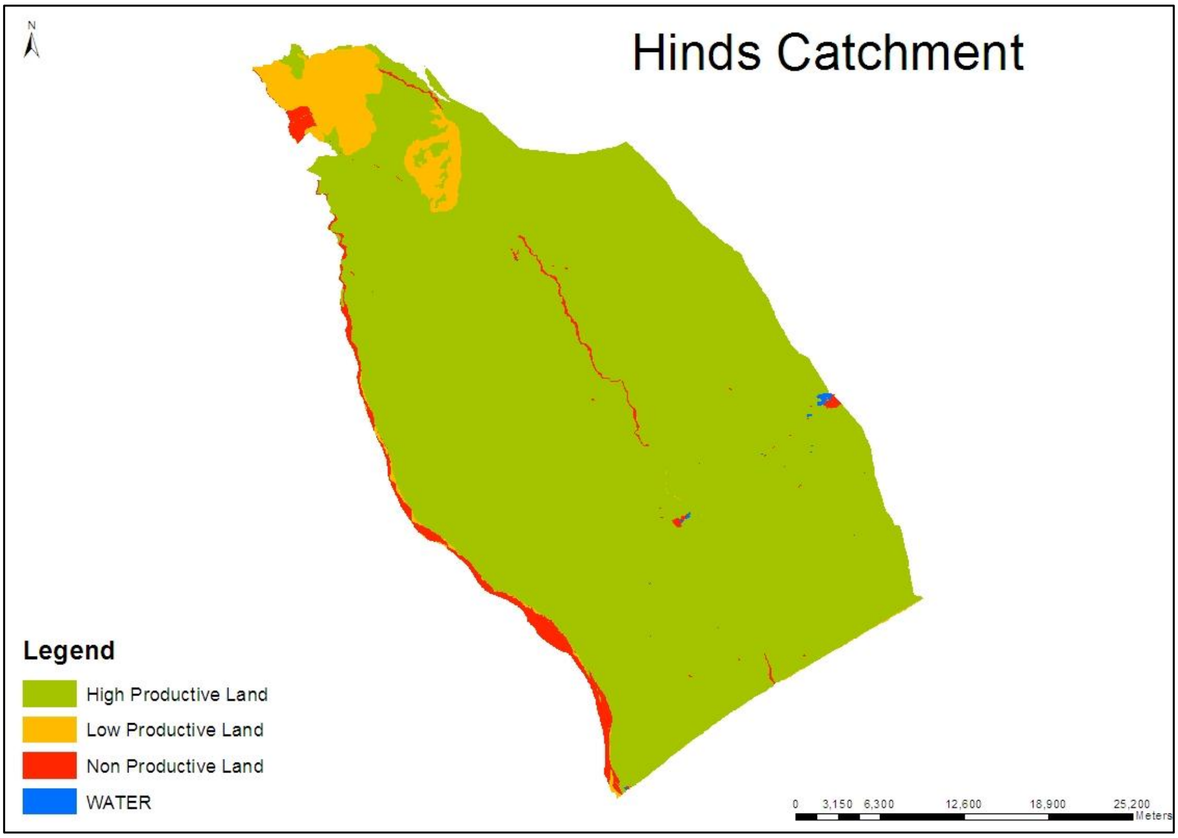
The equal allocation approach, which is a variant of the average allocation approach, allocates the same nutrient discharge allowance all eligible landowners in a given nutrient management zone (NMZ) in the catchment (Lilburne & Webb, 2012), regardless of their land use. This approach differs to the average allocation approach in the calculation of the allowance value. The catchment is divided into high, low, and non-productive NMZ categories. Maximum likely leaching total from the low and non-productive zones are determined and then subtracted from the total leaching limit[9]. The remainder is allocated equally to the high productivity land, ie, to the land with the greatest potential for intensification. Under this approach those with leakier soils on the high productivity land may have to apply more mitigation options than those with lower leaching. An implicit outcome of this approach is to provide an economic incentive and the flexibility to encourage landowners of good quality land to increase their level of intensification and to penalise owners of land that is prone to high leaching, thus reducing their land use intensity.

For this allocation approach the Hinds catchment is divided in to three NZFARM zones based on NMZ – High productive land (HPL), Low productive land (LPL) and Non-productive land (NPL). Landowners were allowed to trade within their zone, but not across zones. This

[9] The maximum likely leaching limit for the LPL zone is roughly the average rate of dryland sheep and beef, while the leaching limit for the NPL zone is approximately the average rate of exotic forestry.

restriction does not pose a significant impediment in this catchment as a majority of the land (and N leaching) is in the HPL zone (Figure 15).

Figure 15: NZFARM zones based on nutrient management zones (NZM)



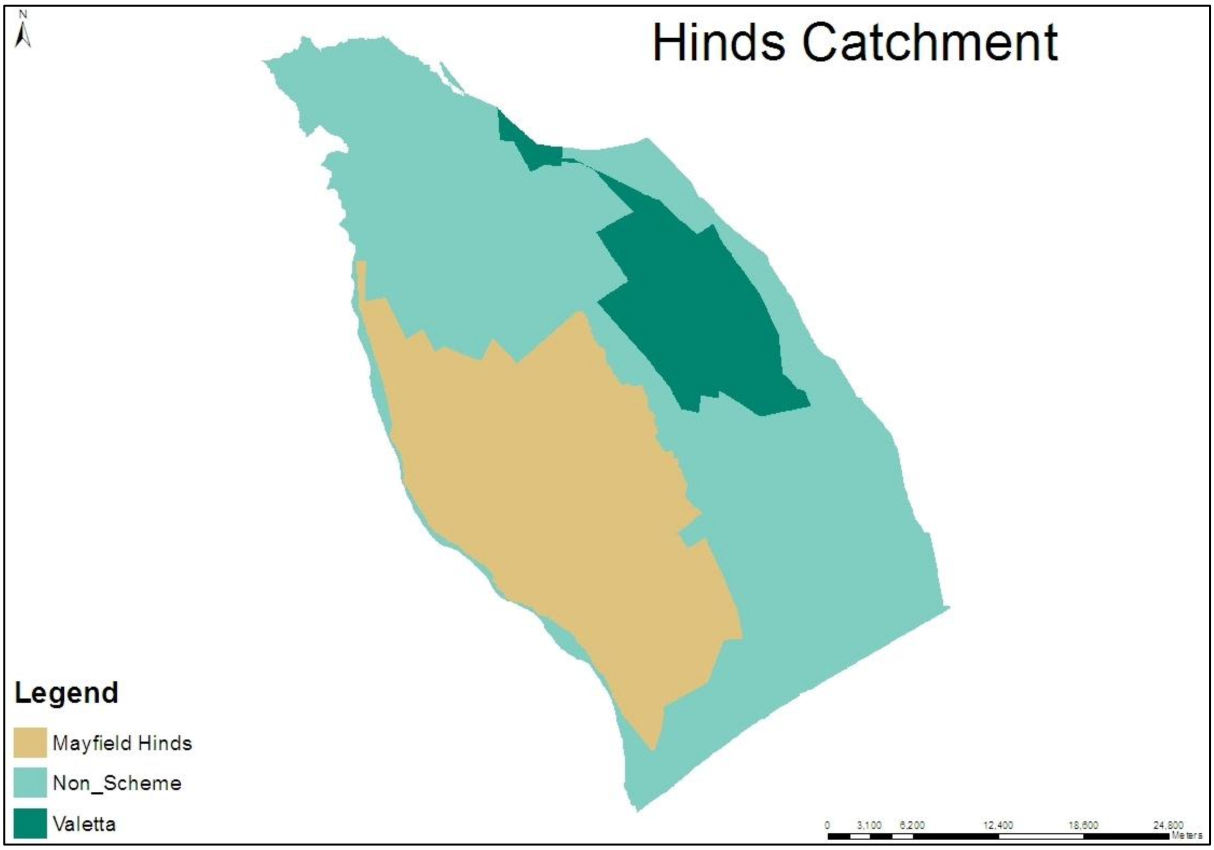
Catchment club allocation, and a restricted cap and trade programme

This policy scenario is similar to the catchment-wide cap and trade programme above, except that allowances can only be traded within a given sub-region (eg, NZFARM zones) in the catchment instead of anywhere within the greater catchment. Landowners in the 'club' are allocated allowances based the grandparenting approach, but they can only buy or sell allowances with others who are members of their particular NZFARM zone ('club'). This scenario is more restrictive than trading across the whole catchment as there are in total, fewer allowances to trade in a 'club' market, which could result in higher costs. It may be less costly to administer though because the regulatory agency would not have to oversee trading between all landowners in the catchment. It may also result in lower transaction costs for those who are members of the 'club' as it would be relatively easy to locate nearby farmers who are willing to trade. Restricting the trading to only within a 'club' is likely to increase the cost of compliance for those that do not belong to a 'club'.

This scenario may reduce potential ‘hotspot’ issues. ‘Hotspots’ can occur where, for instance, a downstream discharger sells NDAs to an upstream discharger, and increase the nutrient concentrations upstream. ‘Clubs’, by restricting the trading spatial area, can reduce this risk.

For this scenario, the Hinds catchment is divided in to three NZFARM zones – the Mayfield Hinds, and Valetta Irrigation scheme area, and land outside the Irrigation schemes (see Figure 16) Landowners in the Mayfield-Hinds and Valetta zone are allocated NDAs based on a grandparent allocation approach and allowed to trade them within that particular ‘club’. Landowners in the non-scheme zones were given an average allocation and not allowed to trade. Note that this delineation of ‘clubs’ based on the main irrigation schemes is only one of a range of possibilities in the catchment. In reality, there is the potential for several clubs to be created based on a range of criteria.

Figure 16: NZFARM zones for catchment clubs based on Irrigation schemes



A summary of the scenarios considered in this report, including advantages and disadvantages of each is included in Table 6.

Table 6: Summary of water quality policy scenarios

Policy	Principle	Key Features	Advantages	Disadvantages
Require Adoption of Land Management Practices	Farmers are required to adopt land management practices to reduce nutrient leaching	Regulator develops a list of acceptable practices that landowners must implement	Relatively easy to administer and monitor Rewards landowners who have already implemented approved management practices to increase the efficiency of their production systems	Regulator tasked with picking 'winning' practices Participants restricted by choice of management practices to implement.(some practice may not fit their context either physical location or farm management planning) There is uncertainty around the actual reduction in nutrient leaching within the catchment The implementation of these practices alone may not meet water quality objectives. Water quality may continue to decline as it does not limit further intensification
Farm- Specific Cap (no trading)	Catchment N leaching cap is established Catchment cap is allocated according to various allocation rules in the form of allowances to each landowner Trading is not allowed	Existing land use and land management allowed to continue if landowner does not leach more nutrients than they are allocated	Landowners can implement any nutrient mitigation practices as long as they don't leach more than they are allocated. Farm-specific cap can vary between landowners in a catchment depending on allocation approach	Landowners have limited flexibility in achieving their reduction requirements as they not allowed to trade Costs could be significant for those landowners who leach more nutrients than they are allocated Requires the benchmarking of all farms in catchment to determine whether they are above or below the allowances they were allocated If the catchment nutrient reduction target is high then there could large changes in land values
Cap-and-trade with Free Allocation	Catchment N leaching cap is established Catchment cap is allocated according to various allocation rules in the form of allowances to each landowner Allowances can be traded between landowners	Existing land use and land management allowed to continue if landowner does not leach more nutrients than they are allocated Any increases in nutrient leaching on a specific farm can be offset by reductions elsewhere in the catchment	Provides landowners flexibility as: • Landowners can implement any nutrient mitigation practices as long as they don't leach more than they are allocated • Landowners can intensify their production (and therefore nutrient leaching) as long as they can purchase reduction in nutrient leaching from another landowner Likely to be more cost-effective than a catchment cap with no trading	Even with trading costs could be significant for those landowners who leach more nutrients than they are allocated Requires the benchmarking of all farms in catchment to determine whether they are above or below the allowances they were allocated Additional cost to track and register trades Could result in some hotspot, where nutrient concentrations increase in certain reaches of the waterway (catchment club scenario potentially reduces this risk)

Policy	Principle	Key Features	Advantages	Disadvantages
Cap-and-trade with Auction-based allocation	Catchment N leaching cap is established Initial allocation is determined when allowances are purchased by landowners in an auction Allowances can be traded between landowners	Discharge allowances goes to highest bidders Existing land use and land management allowed to continue if landowner does not leach more nutrients than they are allocated Any increases in nutrient leaching on a specific farm can be offset by reductions elsewhere in the catchment	Provides landowners flexibility as: • Landowners can implement any nutrient mitigation practices as long as they don't leach more than they are allocated. • Landowners can intensify their production (and therefore nutrient leaching) as long as they can purchase reduction in nutrient leaching from another landowner Revenue generated from sale of allowances could be used to offset council or landowner costs of the policy or to fund additional water quality improvement initiatives	Even with trading costs could be significant for those landowners who leach more nutrients than the number of allowances they purchased Requires the benchmarking of all farms in catchment to determine whether they are above or below the allowances they purchased Additional cost to run and auction and track and register trades Could result in some hotspot, where nutrient concentrations increase in certain reaches of the waterway Transfers wealth from landowners to the council may be unfavourable politically Uncertainty of cost of nutrient discharge allowances
Resource Rent	Nutrient leaching is charged a rental fee (tax) on a $ per kg basis	Rental fee is charged in addition to requiring landowners meet their N leaching cap	Revenue generated from the rent could be used to offset council or landowner costs of the policy or fund additional water quality improvement initiatives	Additional charge could further disadvantage landowners that are already financially burdened by having to meet their N leaching cap

4 Baseline calibration of NZFARM for Hinds Catchment

This chapter outlines the key outputs of the baseline calibration of NZFARM for the Hinds catchment. Note that we include two 'no-policy' scenarios here: current land use and a likely 'development' scenario. The extension of Rangitata Diversion Race is projected to add approximately 30,000 ha of new irrigated land in the catchment. Land use change projections for the 'development' scenario that correspond to the increased irrigation area are based on assumptions from the Hinds Zone Committee.[10] Both 'no-policy' scenarios assume that farmers implement typical (base) farm management practices. This assumption was made so that our baseline estimates are consistent with 'no-policy' N leaching estimates developed by ECan. The net revenue, N leaching, and land use area estimated for the development scenario serves as the no policy 'baseline' modelled in NZFARM. All the nutrient reduction policy scenarios in Chapter 5 are compared with this baseline.

Current Land Use – no nutrient reduction policy

The current land use scenario assumes that there is no water quality improvement policy in place and that all landowners are currently doing 'base' management practices. This is relatively consistent with the assumptions that were made in the baseline modelling done by ECan to establish N leaching total from diffuse sources in the catchment (ECan, 2013b).

According to the current land use map, the Hinds catchment comprises nearly 139,000 ha, of which about 85,000 ha are under irrigated enterprises. Sheep and beef and dairy farming enterprises dominate the catchment. These enterprise areas are a key input to the NZFARM and serve as a good 'check' that the baseline calibration is acceptable. After the initial model simulation, the areas estimated in NZFARM are compared to the areas from the land use map to verify that the model is producing estimates within an acceptable range of the inputs data (ie, minimal change from the original data). Table 7 shows the calibrated land area in NZFARM compared to the area in the current land use map. All enterprise areas are within 2% of the land use map areas.

A summary of the key economic and environmental outputs is listed in Table 8 and production outputs are listed in Table 9. Total net catchment income from land-based operations with the current land use mix is estimated at NZ$247 million. Total N leached from diffuse sources is estimated to be about 4,628 tN/yr, while P loss is about 105 tP/year. This equates to an average of about 34.2 kgN/ha and 0.8 kgP/ha across all land in the catchment.

[10] More details can be found online at http://ecan.govt.nz/our-responsibilities/regional-plans/regional-plans-under-development/hinds/Pages/community-involvement.aspx

Table 7: Catchment enterprise area ('000 ha), current land use, no policy

Enterprise	Current Land Use		
	Land Use Map	NZFARM Calibration	% Difference
Dairy_1	7.2	7.2	0%
Dairy_2	37.0	37.0	0%
DairySup_1	8.2	8.3	0%
DairySup_2	2.9	2.9	0%
Arable_1	1.2	1.2	0%
Arable_2	11.2	11.2	0%
Arable_3	14.4	14.4	0%
Arable_4	1.3	1.2	-1%
SNB_1	23.4	23.5	0%
SNB_2	20.4	20.3	-1%
SNB_hill	6.8	6.8	0%
Pigs	0.1	0.1	0%
Berryfruit	0.3	0.3	0%
Grapes*	0.0	0.0	1%
Pine	2.0	2.0	0%
Native	0.8	0.8	0%

* Land area under Grapes is only about 12 ha.

Table 8: Key outputs, current land use, no policy

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$167.3	$37.3	$0.0	2,515	34	464,414	43.6
Dairy Support	$12.8	$4.1	$0.0	620	5	6,778	11.0
Arable	$40.0	$10.4	$0.0	629	10	23,125	27.7
Sheep & Beef	$21.6	$5.4	$0.0	860	56	210,508	49.8
Horticulture	$3.6	$1.8	$0.0	3	0	837	0.3
Forestry	$1.3	$0.4	$0.0	2	0	-31,160	2.0
Other	$0.1	$0.0	$0.0	1	0	238	0.9
Total	$246.7	$59.3	$0.0	4,628	105	674,739	135.4

* Total GHGs are greenhouse gas emissions from on-farm activities and include the annual increment in carbon sequestration from forests. 'Horticulture' includes Grapes and Berryfruit. 'Other' includes Pigs and Native forestry

Table 9: Farm-level production, current land use, no policy

Product	Units	Production Output
Milk Solids	tonnes	61,639
Animals	thousand head	91
Meat	tonnes	44,794
Wool	tonnes	739
Fruit	tonnes	2,709
Wheat and Barley	tonnes	108,852
Silage	tonnes	48,630
Vegetables	tonnes	27,610
Seeds	tonnes	9,026
Straw	thousand bales	139
Timber and Pulp	thousand m3	27

The variation in N leaching and P loss rates on a kg per ha under current land use is shown in Figure 17 and Figure 18, respectively. These figures illustrate how nutrient leaching rates can vary widely for the same enterprise because of differences in location, stocking rate, soil type, irrigation scheme, fertiliser application, and management practices.

Figure 17: N leaching (kg/ha) under current land use across the catchment

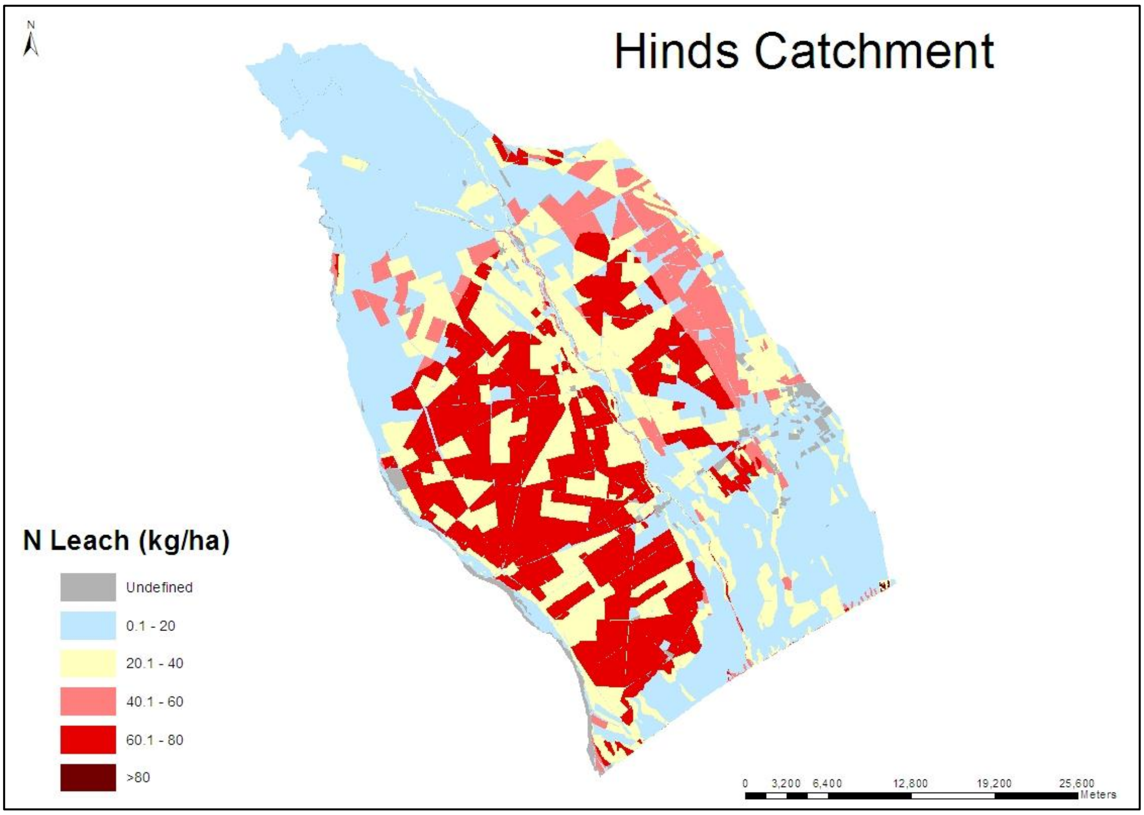


Figure 18: P losses (kg/ha) under current land use across the catchment

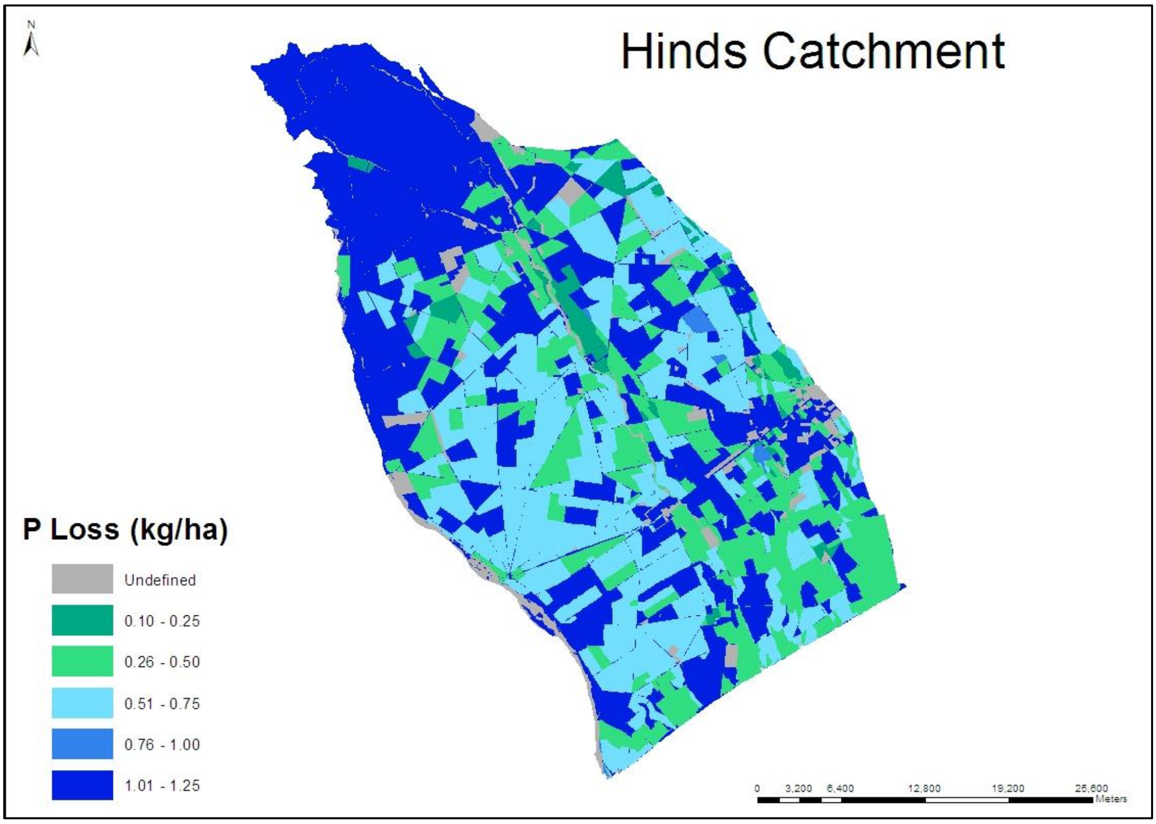


Figure 19 shows the distribution in total GHG emissions across the catchment, under current land uses. Figure 20 and Figure 21 show the distribution of farm net revenue (EBIT) and cash farm surplus on a per ha basis, respectively.

Figure 19: GHG Emissions (kg/ha) under current land use across the catchment

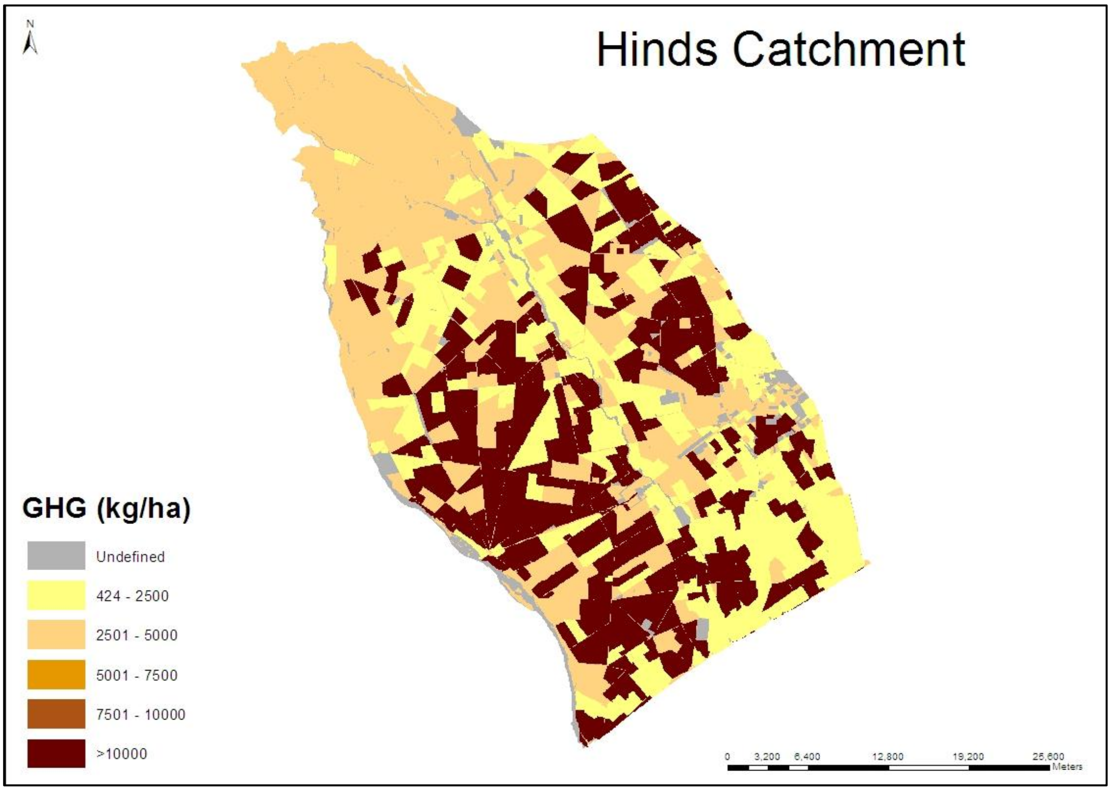


Figure 20: Farm net revenue ($/ha) under current land use across the catchment

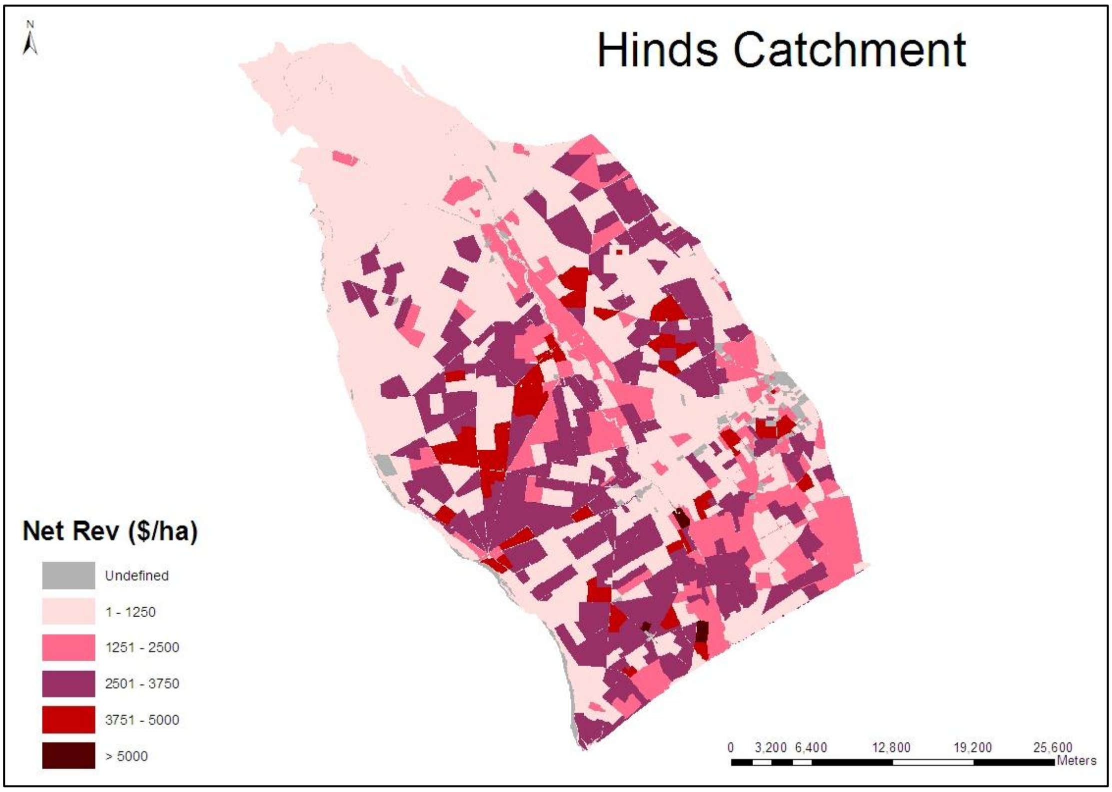
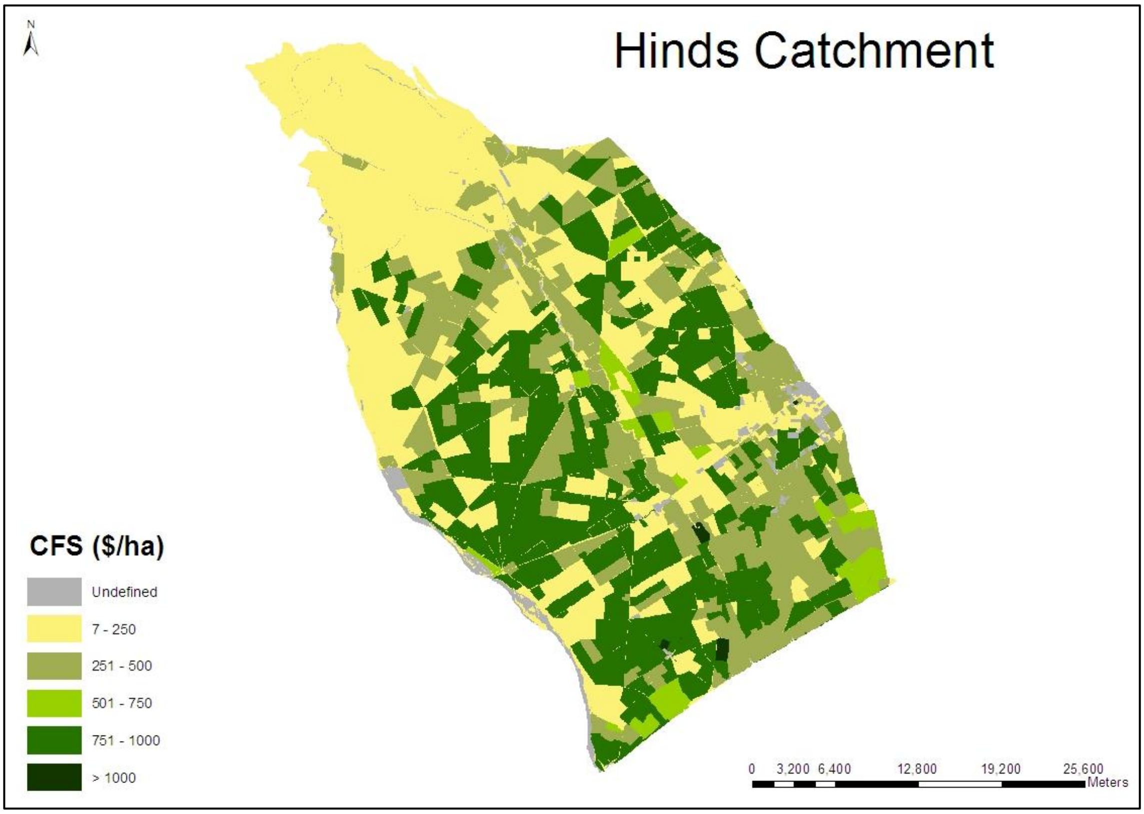


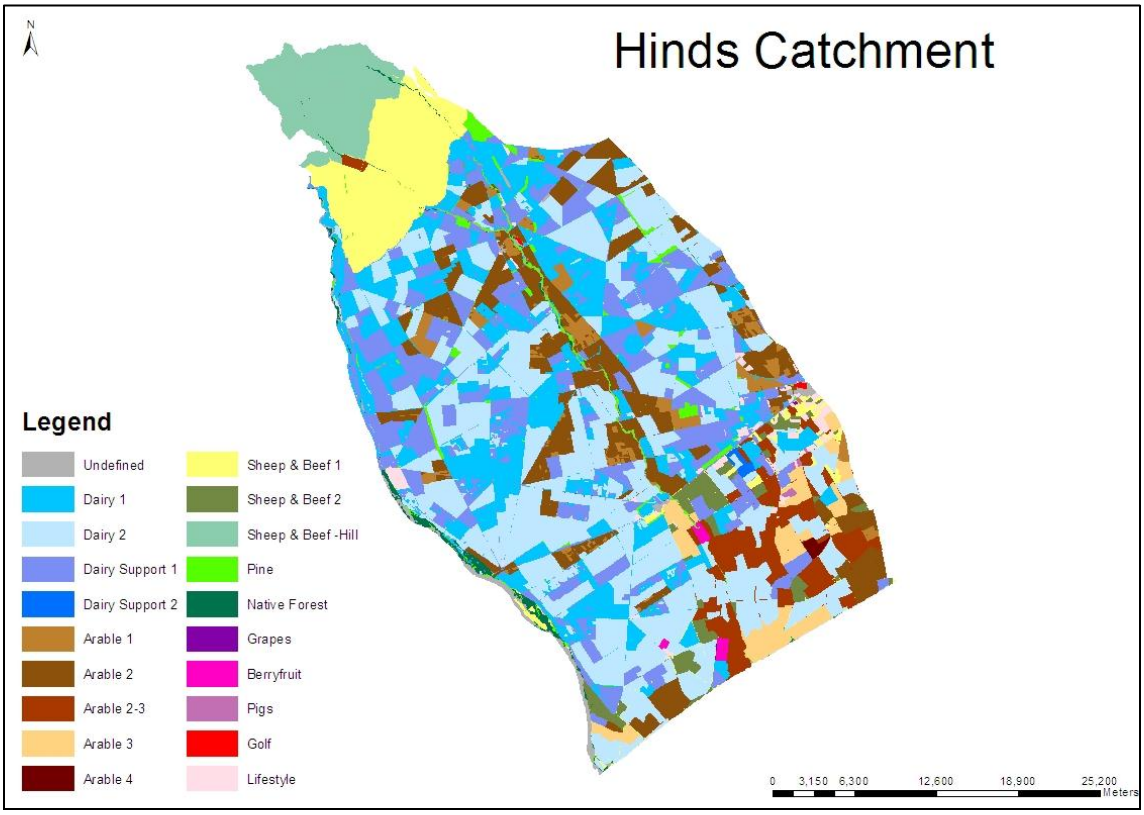
Figure 21: Cash farm surplus ($/ha) under current land use across the catchment



Development Scenario –no nutrient reduction policy (NZFARM Model Baseline)

Under the development scenario the area of irrigated land in the Hinds catchment increases by 30,000 ha. With the increased availability of irrigation water, it is assumed that most of the land used for sheep and beef farming would shift to dairy platform and dairy support (ECan, 2013a). The results of the various policy scenarios (see Section 5) were compared to the development scenario. Figure 22 shows the mix of land uses in the catchment as a result of the increased irrigation area.

Figure 22: Development Scenario Land Use



With the additional irrigation, the dairy comprises about 47% of the catchment, followed by arable (20%), dairy support (16%), and sheep and beef (14%). Table 10 shows the calibrated land area and the area in the development scenario land use map. Again, there is minimal difference between the land use map areas that are used as input to NZFARM and the areas estimated by the calibrated baseline.

Table 10: Catchment enterprise area ('000 ha), development scenario (no policy baseline)

Enterprise	Development Scenario Land Use		
	Land Use Map	NZFARM Calibration	% Difference
Dairy_1	24.0	24.0	0%
Dairy_2	40.1	40.1	0%
DairySup_1	21.6	21.7	0%
DairySup_2	0.4	0.4	-4%
Arable_1	3.7	3.7	0%
Arable_2	17.1	17.1	0%
Arable_3	6.8	6.9	0%
Arable_4	0.3	0.3	-3%
SNB_1	10.2	10.2	0%
SNB_2	2.8	2.7	-3%
SNB_hill	6.8	6.8	0%
Pigs	0.1	0.1	0%
Berryfruit	0.3	0.3	0%
Grapes	0.0	0.0	1%
Pine	2.0	2.0	0%
Native	0.8	0.8	0%

With increased irrigation most of the land in sheep and beef farming enterprises is expected to shift to dairy and dairy support enterprises. Total net catchment income from land-based operations in the development scenario is estimated at NZ$338 million. Total N leached is about 5,860 tN/yr, while P loss is about 92 tP/yr.[11] This equates to an average of about 43.3 kgN/ha and 0.7 kgP/ha across all land in the catchment. A summary of the key economic and environmental outputs for the development scenario is listed in Table 11and production outputs are listed in Table 12. ***All the policy scenarios in the next chapter are compared with these estimates for the development scenario.***

[11] P loss is higher for SNB (Sheep, beef and deer) enterprises (See Table 42 in Appendix 1)

Table 11: Key outputs, development scenario (no policy baseline)

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$251.0	$54.7	$0.0	3,606	48	699,957	64.1
Dairy Sup	$25.1	$7.1	$0.0	1,348	11	14,533	21.7
Arable	$47.6	$12.5	$0.0	691	10	25,088	27.5
Sheep & Beef	$9.3	$2.9	$0.0	209	22	82,082	18.9
Horticulture	$3.6	$1.8	$0.0	3	0	837	0.3
Forestry	$1.3	$0.4	$0.0	2	0	- 31,102	2.0
Other	$0.1	$0.0	$0.0	1	0	238	0.9
Total	**$338.0**	**$79.4**	**$0.0**	**5,860**	**92**	**791,631**	**135.4**

* Total GHGs are greenhouse gas emissions from on-farm activities and include the annual increment in carbon sequestration from forests. 'Horticulture' includes Grapes and Berryfruit. 'Other' includes Pigs and Native forestry

Table 12: Farm-level production, development scenario (no policy baseline)

Product	Units	Production Output
Milk Solids	tonnes	95037
Animals	thousand head	131
Meat	tonnes	28844
Wool	tonnes	521
Fruit	tonnes	2709
Wheat and Barley	tonnes	130182
Silage	tonnes	58926
Vegetables	tonnes	61023
Seeds	tonnes	11151
Straw	thousand bales	170
Timber and Pulp	thousand m3	27

Figure 23 and Figure 24 respectively show the variation in per hectare N leaching and P loss under the development scenario land use. This variation results from differences in factors such as soil type, enterprise, and management across the catchment.

Figure 23: N leaching (kg/ha) under the development scenario

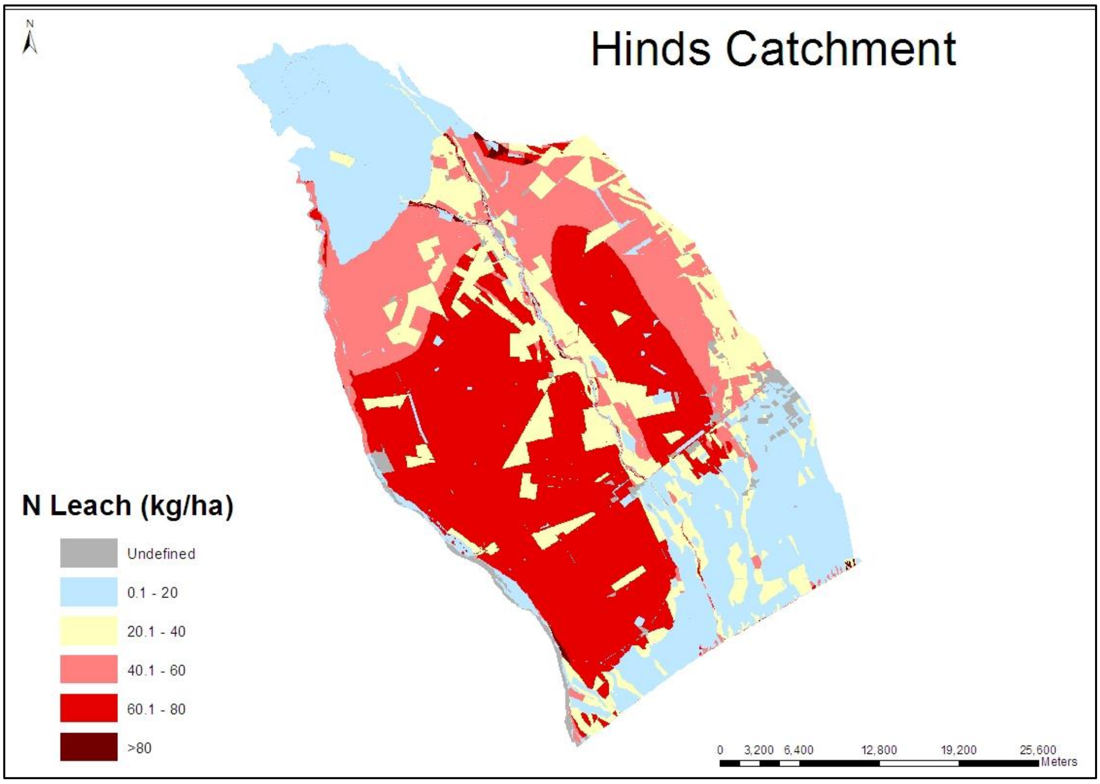


Figure 24: P losses (kg/ha) under the development scenario

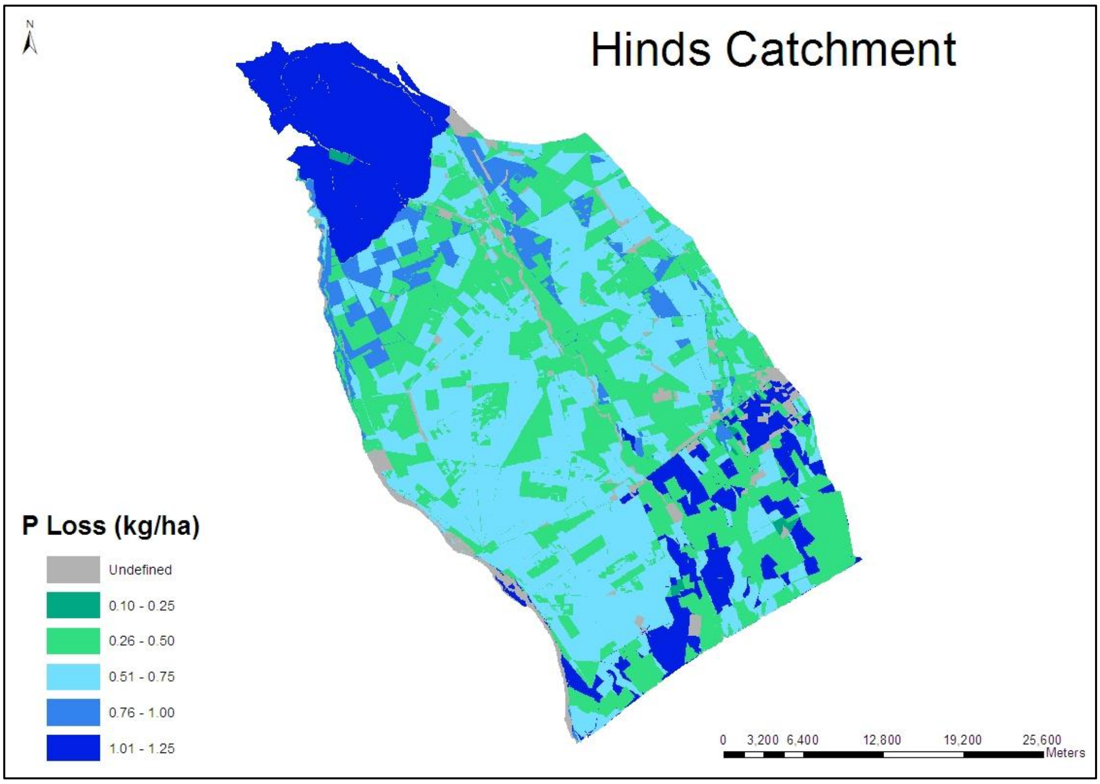


Figure 25 shows the variation in total GHG emissions across the catchment, under the development scenario. Figure 26 and Figure 27 show the distribution of farm net revenue (EBIT) and cash farm surplus on a dollar per ha basis.

Figure 25: Total GHG emissions (kg/ha) under the development scenario

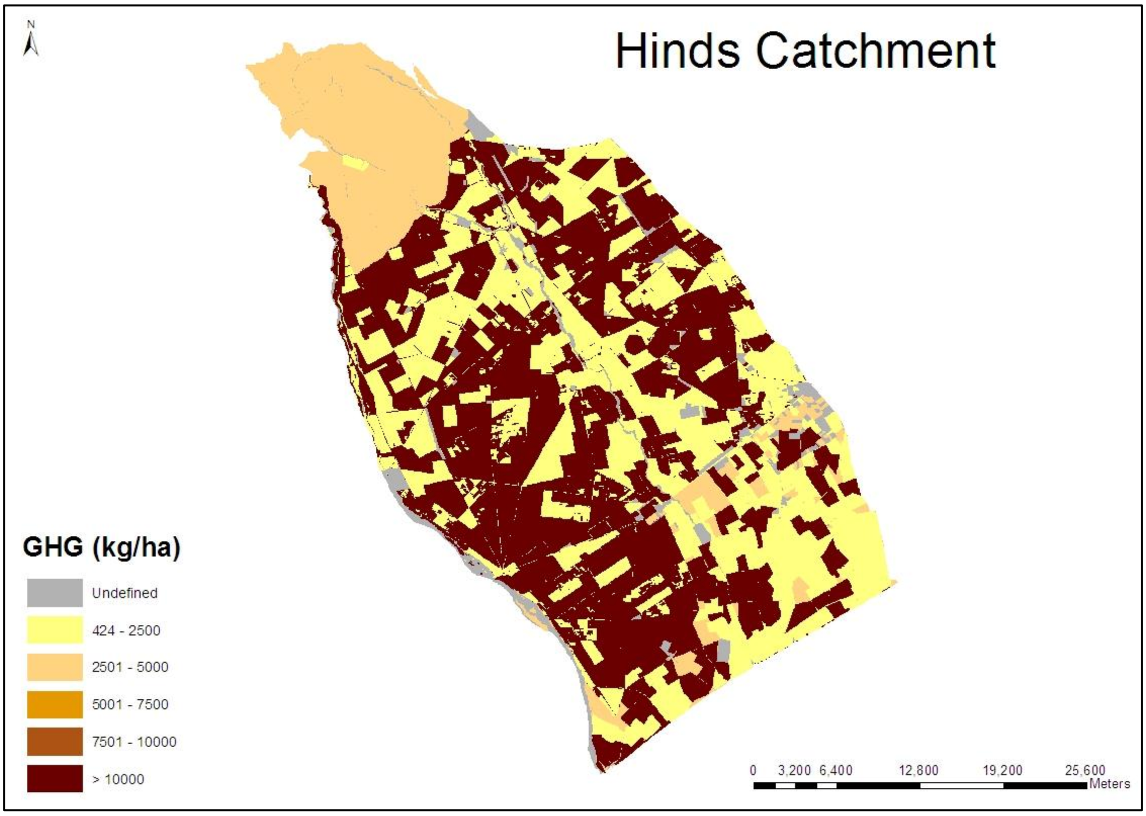


Figure 26: Farm net revenue ($/ha) under the development scenario

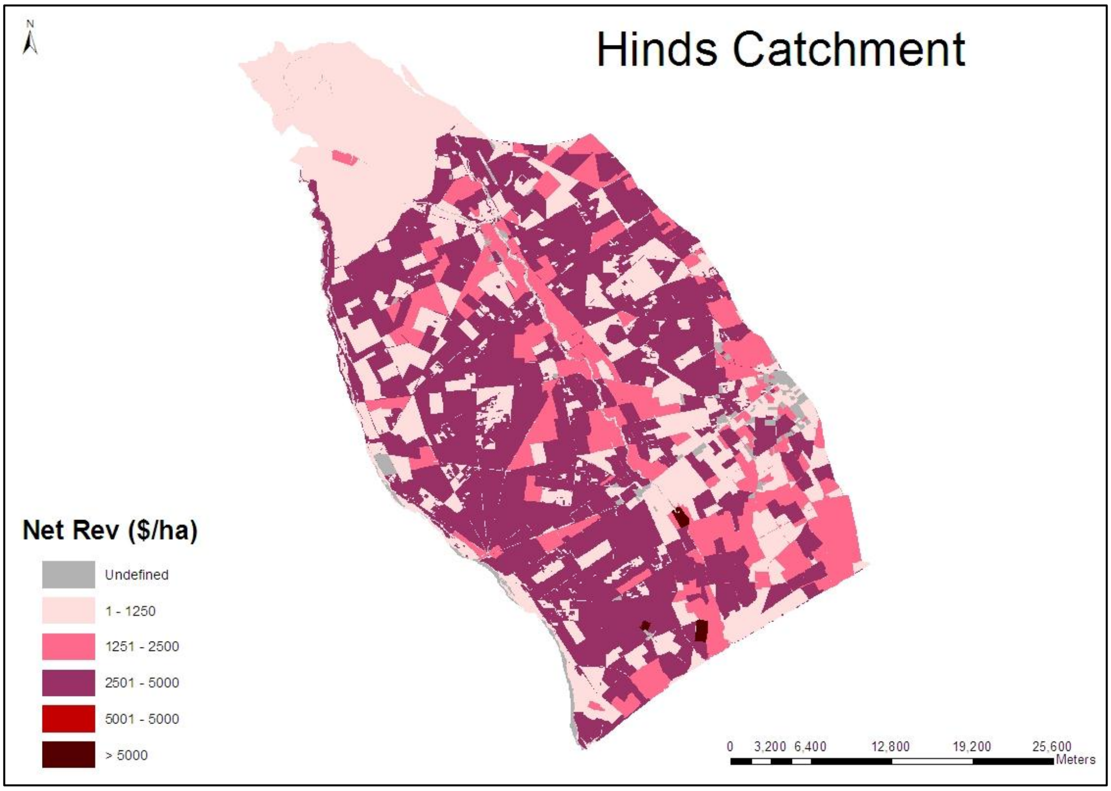
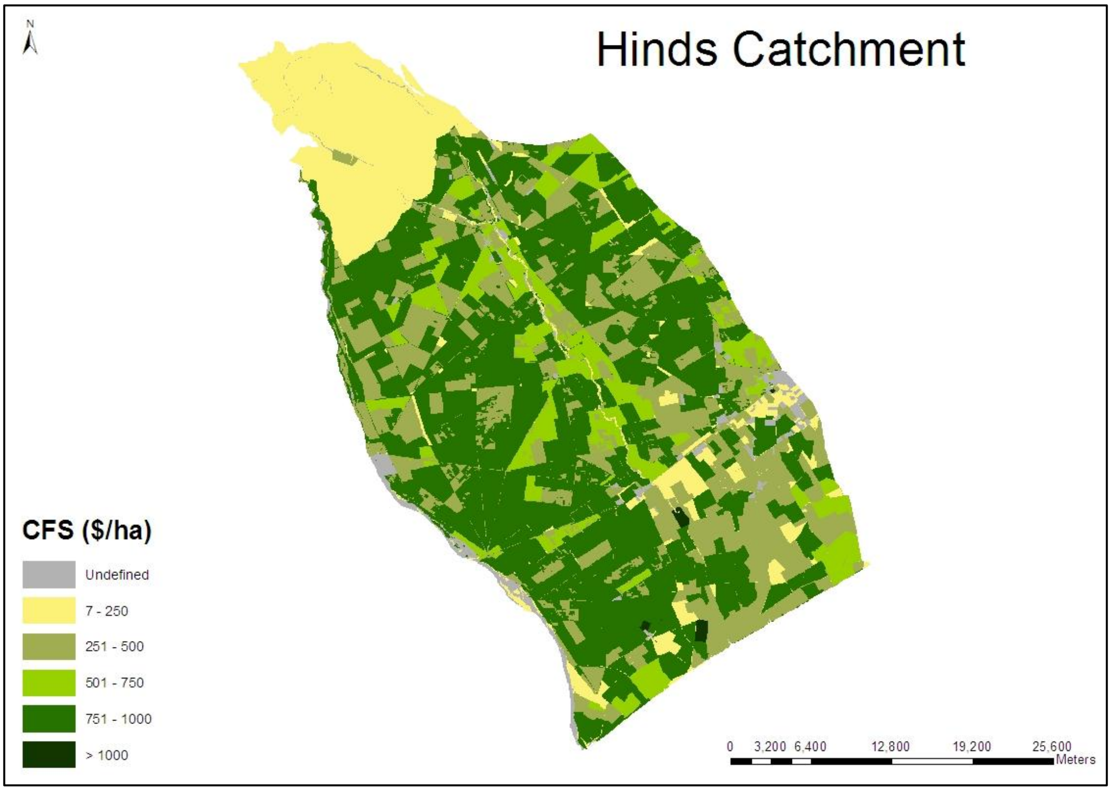


Figure 27: Cash farm surplus ($/ha) under the development scenario



5 Nutrient Reduction Policy Scenario Results

This section reports the economic and environmental impacts of the nine nutrient reduction policy scenarios modelled described in Chapter 3 of this report. The key results reported for each policy scenario include net farm revenue, cash farm surplus, N leaching, average abatement cost, P loss, GHG emissions, enterprise area, and farm level production outputs. All these results are reported for key enterprises and also for the catchment in total. Results disaggregated by NZFARM zones are also reported where applicable. All results are compared to the 'no policy' development scenario with increased irrigated area through extensions to the RDR described in Chapter 4 and hereafter referred to as the '*baseline*'. All the estimates in the main text compare the calibrated baseline to the policy scenario after it has been fully implemented.[12] Key outputs on the dynamic transition of the policy from the baseline to fully-implemented policy are highlighted in Appendix 2. All economic figures are in undiscounted 2013 NZ dollars.

Additionally, a series of maps showing the spatial distribution of the key findings for each policy scenario is presented in Appendix 3. These maps show the spatial variation of cash farm surplus, N leaching, P loss, and GHG emissions on a per hectare basis across Hinds catchment, compared to the baseline. N leaching rates (kg/ha) differ among soil types, thus economic and environmental findings from the nutrient reduction policy scenarios also vary based on the underlying soil distribution across the catchment.

Nutrient Reduction Targets

Environment Canterbury estimates that agricultural land uses in the Hinds catchment currently produce a total N load of 4,422 t/yr (ECan, 2013b). Point sources (ie, sewage) are estimated to contribute an additional 13.4 tN/yr (Loe, 2012) or less than 1 % of the total catchment load. To achieve the water quality outcomes being considered by the Zone Committee, the current load would need to be reduced to an estimated 3,096 tN/yr. The ZC development scenario (our 'no policy' baseline) assumes an additional 30,000 ha of new irrigation that will primarily shift current land use from sheep and beef to dairy and dairy support (ECan, 2013a). ECan estimated that this will increase the total N load from agricultural sources to about 5,612 tN/yr. This indicates achieving the estimated target catchment load of 3,096 tN/yr would require a 45% reduction in the total N load from this baseline.

The NZFARM modelled baseline estimated a total catchment load of 5,860 tN/yr, or a difference of 4% from the Zone Committee estimate. A 45% reduction from this estimated load is approximately 3,240 tN/yr, or 23.9 kgN/ha/yr across the catchment. These are the N leaching figures used to set the N leaching constraints in NZFARM for any binding policy options (eg, caps or max leaching rates) analysed in this report.

[12] For this analysis, we assume that the policy is fully implemented over a relatively long timeframe of 25 years, or to 2038.

A summary of the policy scenario and allocation approaches considered for this report are listed in Table 13. More details on how the amount of each NDA allocated are provided with the results for specific policy scenarios.

Table 13: Overview of NZFARM Nutrient Reduction Policy Scenarios

Policy Scenario	Description	Allocation Approach	Allocation (kgN/ha)	Trading Regime
Baseline (No Policy)	There is no nutrient reduction policy in the catchment and an additional 30,000 ha of new irrigation area in the catchment increases the area of dairy, dairy support, and arable land.	n/a	n/a	n/a
Improving Land Management Practices				
Advanced Mitigation 1 (AM1)	All arable and pastoral landowners required to implement an advanced mitigation 1 bundle of management practices.	None	n/a	None
Farm-Specific Caps (no trading)				
Average Allocation	Each landowner is allocated the same number of NDAs regardless of their location in the catchment or their land use.	Average	23.9	None
Natural Capital Allocation	Each landowner is allocated NDAs based on a land use capability classification (which is a proxy for natural capital) where more productive land is allocated more NDAs.	Natural capital as defined in Lilburne et al (2013)	2.5 to 33.1	None
Catchment-wide Cap and Trade				
Grandparent Allocation + Trading	Each landowner is freely allocated NDAs based on a 45% reduction in N leaching from their existing (or reference year) N leaching rate.	Grandparenting	0 to 47.6 (average of 23.9)	Catchment-wide
Nutrient Vulnerability Allocation + Trading	Each landowner is freely allocated NDAs using a nutrient vulnerability classification based on the nutrient filtering capacity of the soil and higher leaching land is allocated more NDAs.	Nutrient vulnerability class as defined in Webb et al (2010)	10.3 to 27.7	Catchment-wide
Auction Allocation + Trading	NDAs are allocated using an auction mechanism.	Auction	Varies (average of 23.9)	Catchment-wide
Hybrid Approach				
Grandparent Allocation + Resource Rent	Each landowner is allocated NDAs based on a 45% reduction in N leaching from their existing (or reference year) N leaching rate and have to pay an annual resource rent of $2.50/kg N leached.	Grandparenting	0 to 47.6 (average of 23.9)	Catchment-wide
Equal Allocation + Trading	Landowners are allocated NDAs based on whether their land is classified as high or low productivity land and all land within each class is allocated the same number of NDAs. Land in the higher productivity class is allocated more NDAs.	Land productivity class defined using Lilburne and Webb (2012)	2.0 to 24.8	Restricted to same productive land zones
Catchment Club Allocation + Trading	Landowners within each irrigation scheme (catchment club) are allocated NDAs based on a 45% reduction in N leaching from their existing (or reference year) N leaching rate and allowed to trade. Those landowners outside the clubs are allocated an average allocation for the land area that falls outside of the club and not allowed to trade.	Grandparenting (club) and average (all others)	15.9 to 47.6	Restricted to catchment club zones

*Assumes 30,000 ha of irrigation above current land use

Advanced Mitigation Bundle 1 (AM1) of Practices

This scenario requires all pastoral and arable farmers[13] to adopt an advanced mitigation bundle 1 (AM1) of practices targeted at reducing the total N leaching in the catchment. AM1 practices included in this policy scenario were adopting variable rate irrigation on existing pivot irrigators, variable rate fertiliser application, soil moisture monitoring and applying DCD. They also included the small set of practices assumed to be implemented in the GMPs (compliance) mitigation bundle. Under this scenario, it was assumed that there is no land use change to isolate the effects requiring all farmers to adopt AM1 practices on their existing enterprise. A summary of the changes in key outputs relative to the baseline is listed in Table 14.

Adoption of AM1 practices leads to a 39% reduction in total N leaching in the catchment, falling short of the 45% N reduction target, and additional mechanisms are needed to reduce the remaining 330tN/yr.[14] Results indicated that total net revenue could decrease by 4% while total cash farm surplus decreases by 11%. The average abatement cost, measured as the change in net revenue from the baseline divided by the change in total N leaching, is $5.70/kgN. Total P loss and total GHG emissions were reduced by 12% and 10%, respectively indicating that adoption of AM1 practises targeted at N leaching reductions could result in other environmental benefits.

Table 14: Key outputs, Advanced Mitigation Bundle 1 (AM1) Practices

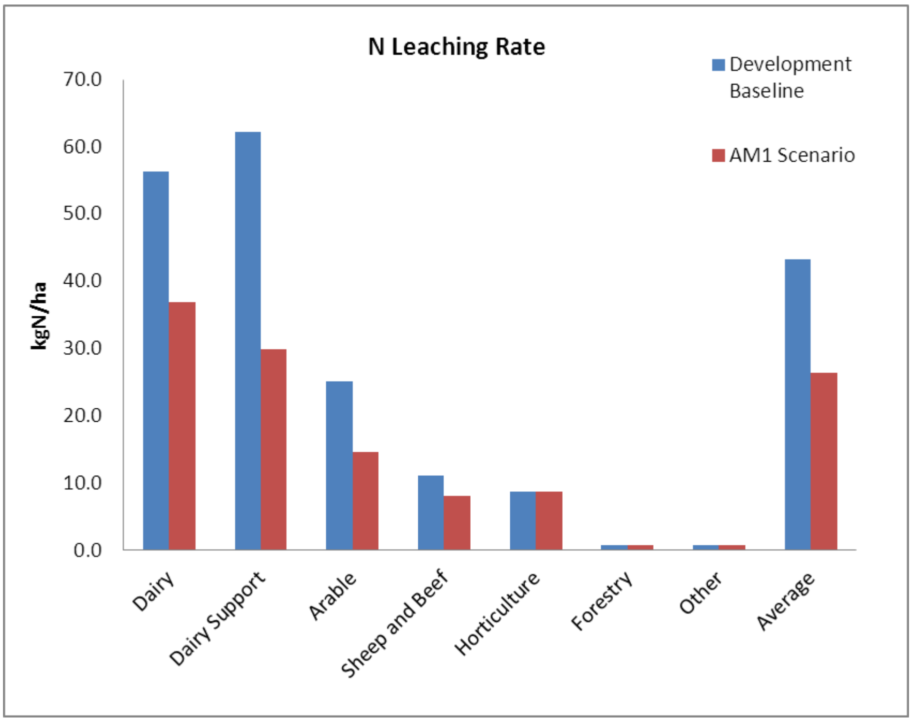
Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$247.6	$52.6	$0.0	2,361	56	630,251	64.1
Dairy Support	$20.5	$3.9	$0.0	648	11	10,878	21.7
Arable	$44.5	$10.4	$0.0	401	6	21,363	27.5
Sheep & Beef	$7.3	$1.6	$0.0	154	8	77,624	18.9
Horticulture	$3.6	$1.8	$0.0	3	0	837	0.3
Forestry	$1.3	$0.4	$0.0	2	0	- 31,195	2.0
Other	$0.1	$0.0	$0.0	1	0	238	0.9
Total	$324.9	$70.7	$0.0	3,570	81	709,995	135.4
Percent Change From Baseline							
Dairy	-1%	-4%	n/a	-35%	15%	-10%	0%
Dairy Support	-18%	-45%	n/a	-52%	-2%	-25%	0%
Arable	-7%	-17%	n/a	-42%	-43%	-15%	0%
Sheep & Beef	-21%	-44%	n/a	-26%	-63%	-5%	0%
Horticulture	0%	0%	n/a	0%	0%	0%	0%
Forestry	0%	0%	n/a	0%	0%	0%	0%
Other	-1%	0%	n/a	0%	0%	0%	0%
Total	-4%	-11%	n/a	-39%	-12%	-10%	0%

[13] No mitigation options were collected or modelled for horticulture, pig and forestry enterprises.

[14] If there is not full compliance with this scenario there will not be the same level of N reduction.

The scenario significantly reduces the overall N leaching rate in the catchment (Figure 28) from 43.3 kg/ha to 26.4 kg/ha. These reductions are from all pastoral and arable farmers in Hinds catchment.

Figure 28: Nutrient leaching rate (kgN/ha) by enterprise, Advanced Mitigation Bundle 1 (AM1) of Practices



This scenario is estimated to reduce production outputs by 1–14% (Table 15). Fruit and forestry output is unchanged, as these enterprises are not required to uptake the AM1 practices.

Table 15: Farm-level production, Advanced Mitigation Bundle 1 (AM1) of Practices

Product	Units	Baseline	Policy Scenario	% Change from Baseline
Milk Solids	tonnes	95,037	93997	-1%
Animals	thousand head	131	128	-2%
Meat	tonnes	28,844	25,764	-11%
Wool	tonnes	521	449	-14%
Fruit	tonnes	2,709	2,709	0%
Wheat and Barley	tonnes	130,182	116,128	-11%
Silage	tonnes	58,926	51,288	-13%
Vegetables	tonnes	61,023	54,969	-10%
Seeds	tonnes	11,151	10,510	-6%
Straw	thousand bales	170	158	-7%
Timber and Pulp	thousand m3	27	27	0%

Average Allocation with no Trading

Table 16: Discharge allowances based on average allocation scenario

NZFARM Zone	Area ('000 ha)	Total N Leaching (tN/yr)		N Leaching Rate (kgN/ha)	
		Baseline	Policy Scenario Allocation	Baseline	Policy Scenario NDA
Entire Catchment	135.4	5860	3240	43.3	23.9

This scenario allocates a 23.9 kgN/ha leaching limit to all landowners in the catchment irrespective of land use and does not include a trading programme to trade N leaching allocations between farmers in the catchment. This scenario only allows the landowners to change their own land management or change land use to meet the 24 kgN/ha limit. A summary of the changes in key outputs relative to the baseline is listed in Table 17.

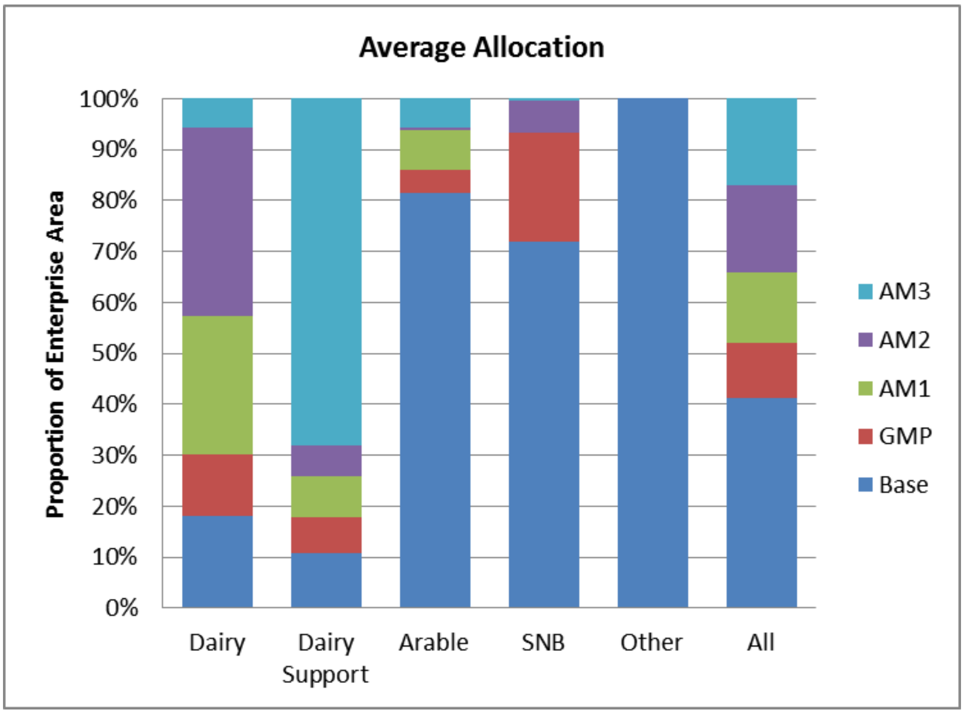
Results show that total net revenue could decrease by 14% while total cash farm surplus decrease by 20% under this scenario. Total N leaching is reduced by 51%, which is beyond the 45% catchment target. This is also because landowners who are already below the allocated N leaching rate would have excess allowances that they cannot sell/trade. Average abatement cost is $15.50/kgN under this scenario. Total P loss and GHG emissions were reduced by 14% and 18%, respectively, indicating that an average allocation with no trading could result in other environmental benefits.

Table 17: Key outputs, Average Allocation with no Trading

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$205.5	$41.8	$0.0	1,508	38	554,506	53.2
Dairy Support	$23.6	$3.4	$0.0	511	6	14,438	27.1
Arable	$44.8	$11.6	$0.0	601	9	23,405	26.7
Sheep & Beef	$11.6	$3.8	$0.0	254	26	101,047	24.2
Horticulture	$4.4	$2.2	$0.0	4	0	1,025	0.4
Forestry	$1.8	$0.5	$0.0	2	0	- 42,687	2.7
Other	$0.1	$0.0	$0.0	1	0	271	1.0
Total	$291.8	$63.3	$0.0	2,881	79	652,004	135.4
Percent Change From Baseline							
Dairy	-18%	-24%	n/a	-58%	-21%	-21%	-17%
Dairy Support	-6%	-52%	n/a	-62%	-50%	-1%	25%
Arable	-6%	-7%	n/a	-13%	-13%	-7%	-3%
Sheep & Beef	25%	28%	n/a	21%	17%	23%	28%
Horticulture	22%	22%	n/a	28%	n/a	22%	23%
Forestry	40%	40%	n/a	35%	n/a	37%	37%
Other	14%	14%	n/a	17%	n/a	14%	11%
Total	-14%	-20%	n/a	-51%	-14%	-18%	0%

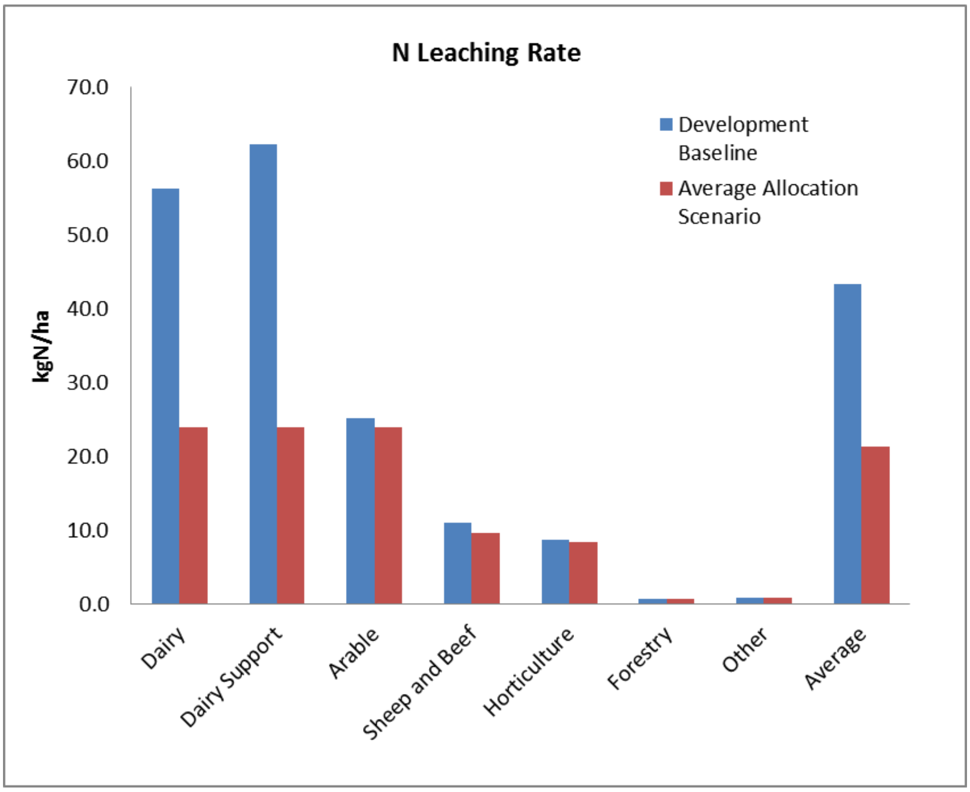
This scenario resulted in significant changes in land use. Landowners were not allowed the flexibility to trade NDAs thus landowners were required to change their land use or land management to meet their N leaching limit. Notable changes occur in sheep and beef (28% increase), dairy support (25% increase), dairy (17% decrease), horticulture (23% increase), and forestry (37%) enterprises. A majority of this land use change is occurring on the very light soils where dairy and dairy support would have to reduce their N leaching by nearly two-thirds to meet the target. Landowners also adjust their land management from baseline practices by adopting mitigation practices, particularly dairy and dairy support (Figure 29). Arable is the least affected enterprise under this scenario.

Figure 29: Proportion of farm practices by enterprise, average allocation with no trading



This scenario significantly reduces the overall N leaching rate in the catchment (Figure 30) from 43.3 kg/ha to 21.3 kg/ha. The majority of these reductions are expected to come from dairy and dairy support enterprises, as landowners must make significant changes in management to achieve the mandated maximum leaching rates.

Figure 30: N leaching rate (kgN/ha) by enterprise, average allocation with no trading



The change in land use and land management decreases dairy-related output by 17% or more (Table 18). Sheep, beef, fruit, and forestry products are estimated to increase between 1 and 40% because the enterprise area expands under this policy scenario. Arable and horticultural production also decreases.

Table 18: Farm-level production, average cap with no trading

Product	Units	Baseline	Policy Scenario	% Change from Baseline
Milk Solids	tonnes	95,037	78,809	-17%
Animals	thousand head	131	107	-18%
Meat	tonnes	28,844	29,192	1%
Wool	tonnes	521	545	5%
Fruit	tonnes	2,709	3319	22%
Wheat and Barley	tonnes	130,182	123,572	-5%
Silage	tonnes	58,926	56,113	-5%
Vegetables	tonnes	61,023	52,755	-14%
Seeds	tonnes	11,151	10,515	-6%
Straw	thousand bales	170	162	-5%
Timber and Pulp	thousand m3	27	38	40%

Natural Capital Allocation with no Trading

This scenario used a natural capital allocation approach to allocate N leaching between landowners, and landowners were unable to trade to achieve their allocated N limit (ie, NDA). For this scenario, the NZFARM zones are based on land use capability (LUC) classes. This approach supports the sustainable use of both land and water resources by allocating higher N leaching limits to more productive land (as defined by LUC). Table 19 shows the NDAs allocated for each NZFARM zone (or LUC). The LUC IV + V zone accounts for a majority of the land in the catchment and the total N allocated to this zone is 21.8kgN/ha. This scenario only allows landowners to change their own land management or change land use to meet the allocated N discharge limit. A summary of the changes in key outputs relative to the baseline is listed in Table 20.

Table 19: Discharge Allowances across the Catchment based on Natural Capital Approach

NZFARM Zone	Area ('000 ha)	Total N Leaching (tN/yr)		N Leaching Rate (kgN/ha)	
		Baseline	Policy Scenario Allocation	Baseline	Policy Scenario NDA
LUC I	0.1	2.7	3	29.3	33.1
LUC II	9.0	277	291	30.8	32.3
LUC III	36.7	933	1072	25.5	29.2
LUC IV and V	78.2	4183	1707	53.5	21.8
LUC VI	9.1	313	113	34.6	12.5
LUC VII	1.9	15	9	7.9	5.0
Total	134.9	5724	3240	42.4	24.0

Results show that total net revenue could decrease by 14% while total cash farm surplus decreases by 22%. This scenario reduces total N leaching by 50%, which is beyond the catchment target. These reductions come at an average abatement cost of $15.90/kgN. Total P loss and GHG emissions were reduced by 16% and 15%, respectively. This indicates that a natural capital allocation with no trading could result in other environmental benefits.

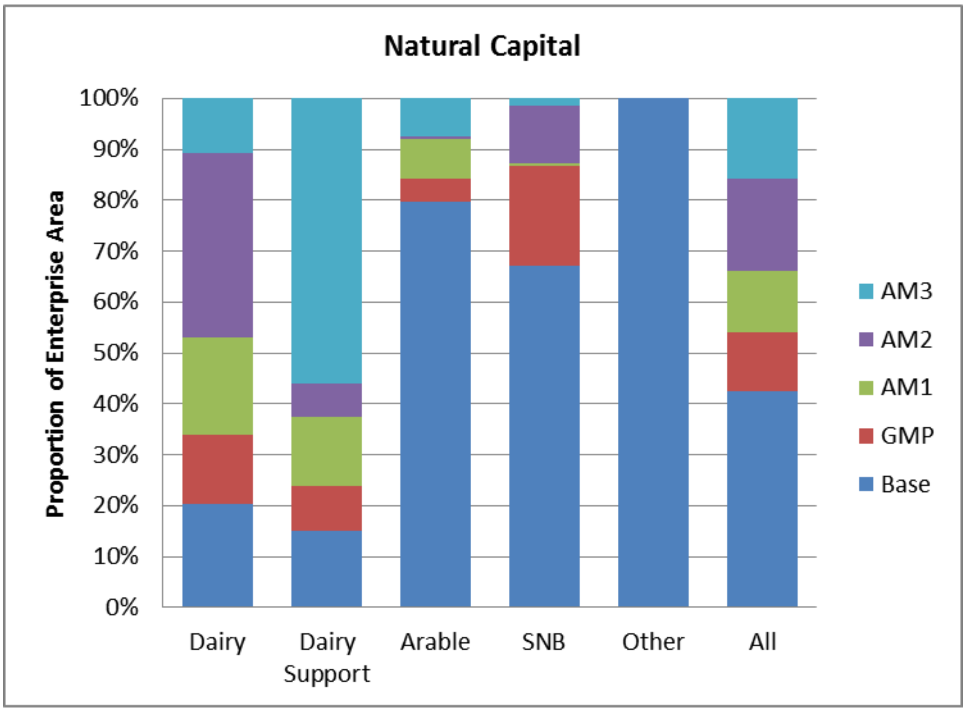
Table 20: Key outputs, natural capital allocation with no trading

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$205.2	$39.90	$0.0	1,499	38	565,466	54.4
Dairy Support	$20.7	$3.37	$0.0	512	6	12,428	23.0
Arable	$47.2	$12.18	$0.0	637	9	24,575	28.0
Sheep & Beef	$11.7	$3.71	$0.0	258	25	103,075	24.6
Horticulture	$4.5	$2.26	$0.0	4	0	1,054	0.4
Forestry	$1.6	$0.44	$0.0	2	0	- 37,495	2.5
Other	$0.1	$0.04	$0.0	1	0	269	1.9
Total	$291.0	$61.9	$0.0	2,912	78	669,373	134.9
Percent Change From Baseline							
Dairy	-18%	-27%	n/a	-58%	-22%	-19%	-15%
Dairy Support	-18%	-52%	n/a	-62%	-48%	-14%	6%
Arable	-1%	-2%	n/a	-8%	-11%	-2%	2%
Sheep & Beef	25%	26%	n/a	23%	12%	26%	28%
Horticulture	26%	26%	n/a	30%	n/a	26%	26%
Forestry	25%	25%	n/a	19%	n/a	21%	34%
Other	13%	13%	n/a	18%	n/a	13%	297%
Total	-14%	-22%	n/a	-50%	-16%	-15%	0%

* Aggregate enterprise area is less than the total area for other policy scenarios because of differences when defining LUC-based zones in ArcGIS. Percentage change is adjusted to reflect this.

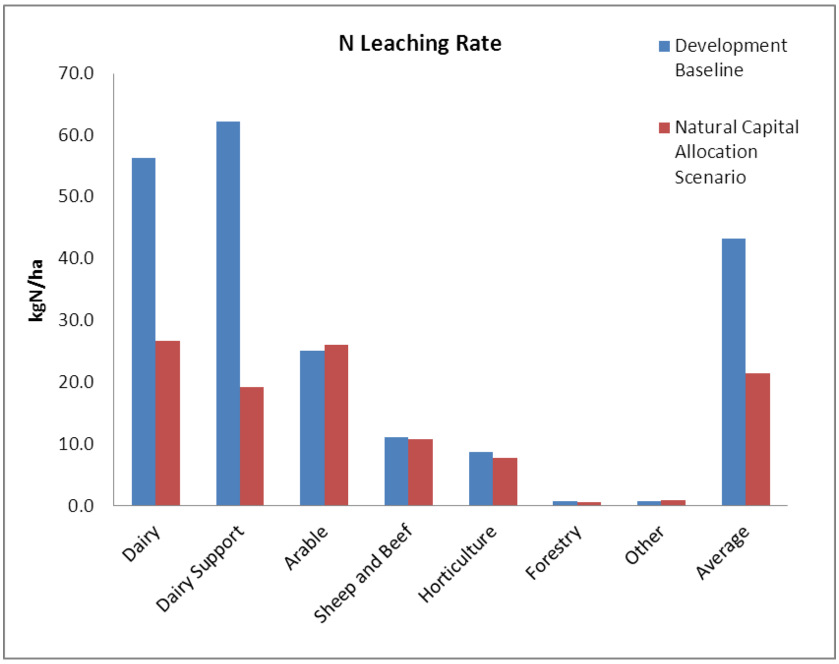
This scenario creates significant changes in land use, notably about 8,000 ha of dairy land switching mainly to sheep and beef farming. These land use changes occur as it is more profitable to switch land use than to adopt land management options to achieve the allocated N limit. Where it is more economical to do so, landowners choose to adopt GMP or advanced mitigation practices to operate within their allocated NDA without changing land use, particularly dairy or dairy support (Figure 31).

Figure 31: Proportion of farm practices by enterprise, natural capital allocation with no trading



This scenario reduces the overall N leaching rate in the catchment (Figure 32) from 43.3 kg/ha to 21.5 kg/ha. A majority of these reductions are expected to come from dairy and dairy support enterprises, as landowners must make significant changes in land use and management to achieve their allocated N leaching limit.

Figure 32: N leaching rate (kgN/ha) by enterprise, natural capital allocation with no trading



As with the average allocation scenario, landowners who are on high leaching soils face higher costs of meeting the target relative to their peers on lower leaching soils. The NDA allocation for LUC IV–VII is less than the 23.9 kgN limit in the average allocation, and therefore landowners in those LUCs would likely face higher costs under this approach

Most dairy-related output decreases by 18% or more (Table 21) as a result of changes in management and land use. Sheep, beef, fruit, and forestry products are estimated to increase between 2 and 25% as the area of these enterprises increase in this scenario.

Table 21: Farm-level production, natural capital allocation with no trading

Product	Units	Baseline	Policy Scenario	% Change from Baseline
Milk Solids	tonnes	95,037	78,342	-18%
Animals	thousand head	131	107	-18%
Meat	tonnes	28,844	29,428	2%
Wool	tonnes	521	552	6%
Fruit	tonnes	2,709	3,416	26%
Wheat and Barley	tonnes	130,182	123,670	-5%
Silage	tonnes	58,926	54,469	-8%
Vegetables	tonnes	61,023	54,491	-11%
Seeds	tonnes	11,151	11,128	0%
Straw	thousand bales	170	168	-1%
Timber and Pulp	thousand m3	27	34	25%

Grandparenting Cap with Trading Programme

To achieve the 45% catchment reduction target, this scenario uses a grandparenting allocation approach which reduces each farm’s N leaching rate by 45%. This is the same as allocating each farm 55% of their baseline N leaching, corresponding to a N leaching rate (or NDA) range between 0 and 47.6 kgN/ha. Catchment-wide trading is also allowed under this scenario. A summary of the changes in key outputs relative to the baseline is listed in Table 22.

Results indicated that total net revenue could decrease by 10% while total cash farm surplus decreases by 15%.Thus achieving the 45% N reduction target comes at an average abatement cost of $12.50/kgN. Total P loss and GHG emissions were also reduced by 13% and 11%, respectively, demonstrating the potential co-benefits of this scenario.

Table 22: Key outputs, grandparenting cap and trade scenario

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$226.9	$48.3	$0.0	2,173	44	611,452	58.0
Dairy Support	$17.9	$1.8	$0.0	267	3	11,304	22.0
Arable	$41.0	$10.5	$0.0	536	8	21,280	24.4
Sheep & Beef	$12.5	$3.9	$0.0	256	25	110,539	26.3
Horticulture	$4.8	$2.4	$0.0	4	0	1,113	0.5
Forestry	$2.1	$0.6	$0.0	3	0	- 49,745	3.2
Other	$0.1	$0.0	$0.0	1	0	297	0.9
Total	$305.3	$67.6	$0.0	3,240	80	706,240	135.4
Percent Change From Baseline							
Dairy	-10%	-12%	n/a	-40%	-10%	-13%	-10%
Dairy Support	-29%	-74%	n/a	-80%	-74%	-22%	2%
Arable	-14%	-16%	n/a	-22%	-23%	-15%	-11%
Sheep & Beef	34%	33%	n/a	22%	14%	35%	40%
Horticulture	33%	33%	n/a	45%	n/a	33%	33%
Forestry	64%	64%	n/a	60%	n/a	60%	61%
Other	25%	25%	n/a	27%	n/a	25%	1%
Total	-10%	-15%	n/a	-45%	-13%	-11%	0%

This modelled scenario estimates that approximately 6,000 ha of dairy and 3,000 ha of arable land would switch to sheep and beef, although forestry, horticulture and dairy support all expand by a few hundred hectares as well. These land use changes occur as it is more profitable to switch land use than to adopt land management options or trade NDAs to achieve the allocated N limit. The policy also incentivises landowners to change their land management practices (Figure 33) to a mix of GMP, or advanced mitigation. Estimates indicate that majority of dairy support farmers adjust their management to AM3 and then sell their excess allowances to other pastoral and arable farmers in the catchment (Figure 34).

Figure 33: Proportion of farm practices by enterprise, grandparenting cap and trade scenario

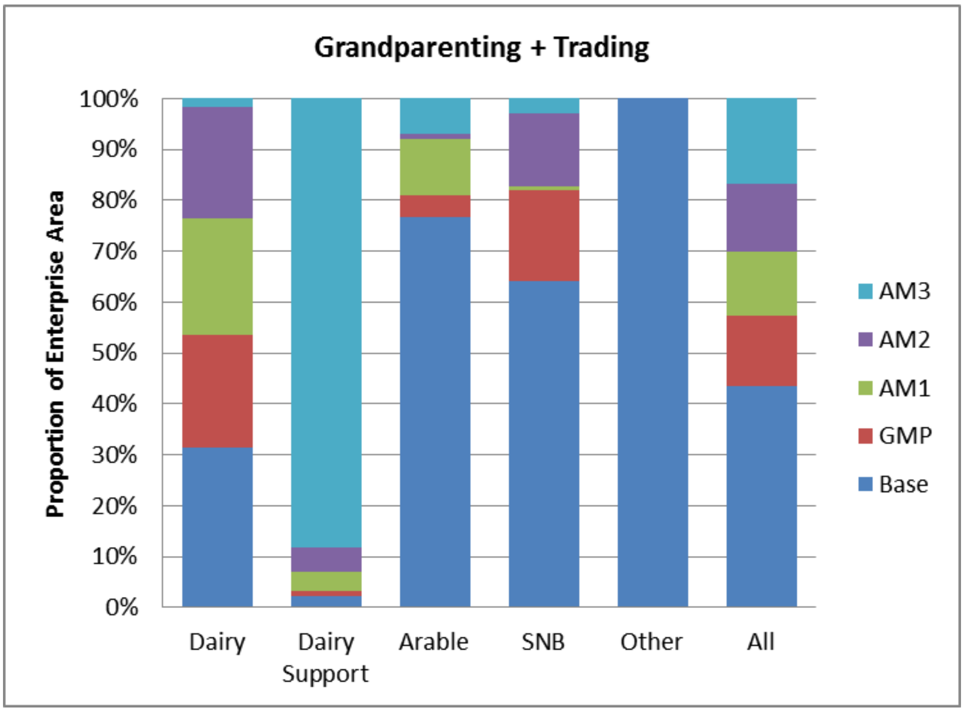
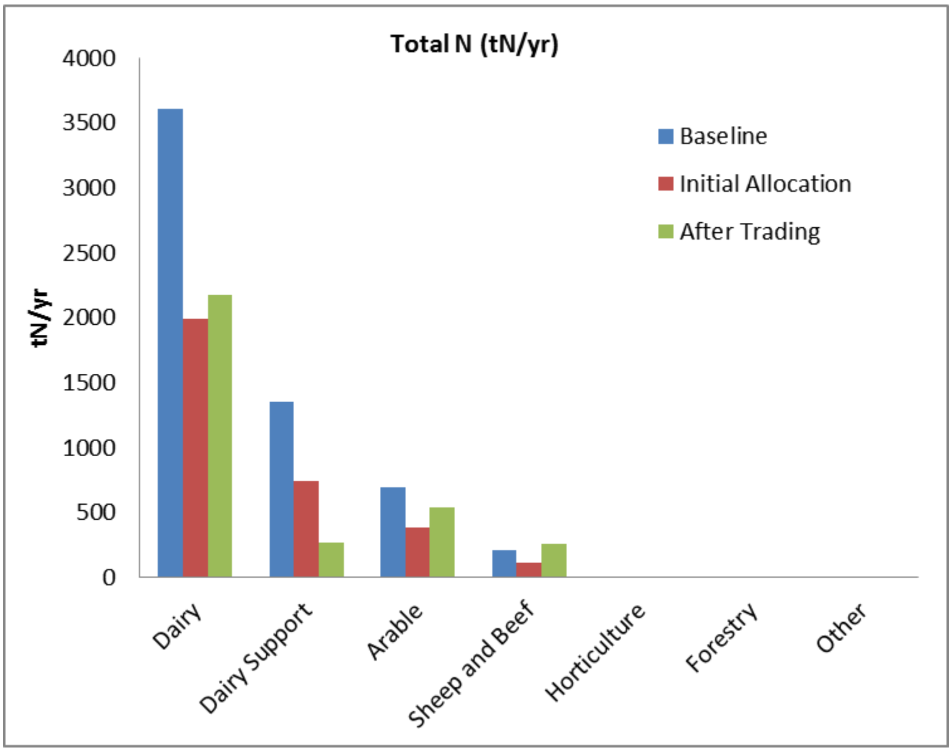
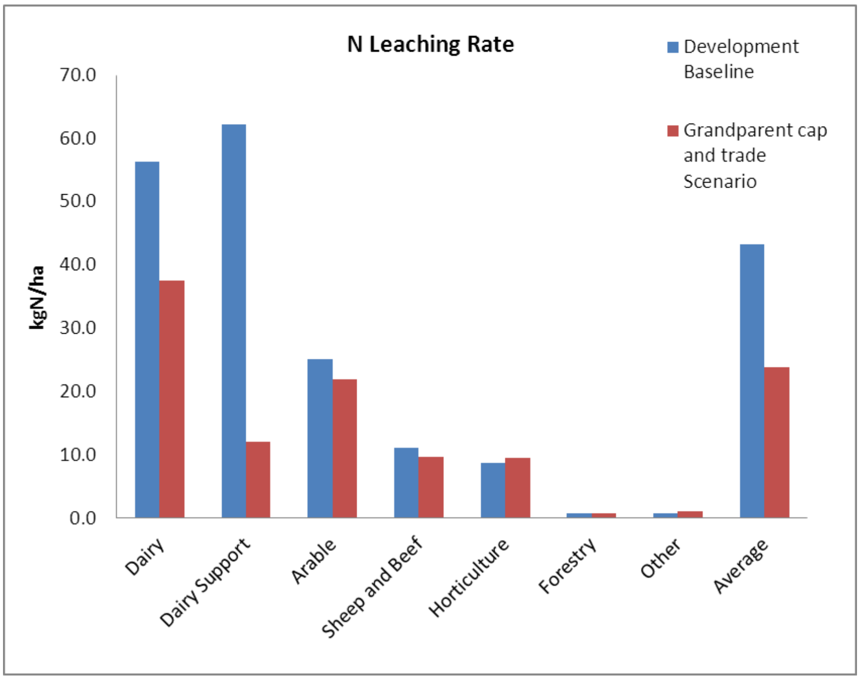


Figure 34: N leaching and allocation (tN/yr) by enterprise, grandparenting cap and trade scenario



This scenario reduces the overall N leaching rate in the catchment (Figure 35) from 43.3 kg/ha to 23.9 kg/ha. A majority of these reductions are expected to come from dairy and dairy support farmers. Horticulture increases slightly because of the relative increase in berryfruit, which has an average leaching rate of 10kgN/ha.

Figure 35: N leaching rate (kgN/ha) by enterprise, grandparenting cap and trade scenario



Most arable and dairy-related output decreases by 9% or more (Table 23). Sheep, beef, fruit, and forestry products are estimated to increase between 3 and 64% as the area of these enterprises expand under this scenario.

Table 23: Farm-level production, grandparent cap and trade scenario

Product	Units	Baseline	Policy Scenario	% Change from Baseline
Milk Solids	Tonnes	95,037	86,663	-9%
Animals	thousand head	131	119	-9%
Meat	Tonnes	28,844	31,063	8%
Wool	Tonnes	521	536	3%
Fruit	Tonnes	2,709	3,607	33%
Wheat and Barley	Tonnes	130,182	108,469	-17%
Silage	Tonnes	58,926	47,066	-20%
Vegetables	Tonnes	61,023	52,921	-13%
Seeds	Tonnes	11,151	9,598	-14%
Straw	thousand bales	170	148	-13%
Timber and Pulp	thousand m3	27	45	64%

Nutrient Vulnerability Allocation Cap with Trading Programme

This scenario uses a nutrient vulnerability approach to allocate the N leaching cap to landowners. This approach uses the level of filtering service provided by the different soils to derive nutrient vulnerability.

For this scenario, there are 6 NZFARM zones based on vulnerability classes – very high, high, medium, low, very low, and other. See Chapter 3 for more details on this allocation approach. Table 24 shows how the NDAs were allocated in each of NZFARM zones. A majority of land in the catchment falls into the 'high' vulnerability zone, with a total of 1920tN/yr allocated to this zone. Trading in this scenario allowed landowners to trade NDAs across the entire catchment. A summary of the changes in key outputs relative to the baseline is listed in Table 25.

Table 24: Discharge allowances based on nutrient vulnerability allocation scenario

NZFARM Zone	Area ('000 ha)	Total N Leaching (tN/yr)		N Leaching Rate (kgN/ha)	
		Baseline	Policy Scenario Allocation	Baseline	Policy Scenario NDA
Very High	8.4	501	232	59.9	27.7
High	80.6	4,505	1,977	55.9	24.5
Medium	15.7	422	364	26.9	23.2
Low	5.4	132	125	24.5	23.2
Very Low	18.1	224	468	12.4	25.9
Other	7.3	76	75	10.4	10.3
Total	135.4	5,860	3,240	43.3	23.9

Results indicated that total net revenue could decrease by 9% while total cash farm surplus decreases by 14%. Thus achieving the 45% N reduction target comes at an average abatement cost of $12.20/kgN. Total P loss and GHGs were also reduced by 9% and 5%, respectively, indicating this scenario potentially has other environmental co-benefits.

Table 25: Key outputs, nutrient vulnerability cap and trade scenario

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$231.4	$49.37	$0.0	2,174	45	621,549	59.4
Dairy Support	$12.0	$1.25	$1.0	177	2	7,598	14.9
Arable	$41.3	$10.62	$2.0	540	8	21,395	24.6
Sheep & Beef	$15.2	$4.65	$3.0	342	29	137,099	32.7
Horticulture	$4.4	$2.19	$4.0	4	0	1,031	0.4
Forestry	$1.5	$0.42	$5.0	2	0	- 36,762	2.4
Other	$0.1	$0.04	$6.0	1	0	277	0.9
Total	$306.0	$68.5	$21.0	3,240	84	752,187	135.4
Percent Change From Baseline							
Dairy	-8%	-10%	n/a	-40%	-8%	-11%	-7%
Dairy Support	-52%	-82%	n/a	-87%	-83%	-48%	-31%
Arable	-13%	-15%	n/a	-22%	-23%	-15%	-10%
Sheep & Beef	63%	58%	n/a	64%	33%	67%	73%
Horticulture	22%	22%	n/a	26%	n/a	23%	24%
Forestry	19%	19%	n/a	4%	n/a	18%	20%
Other	16%	17%	n/a	18%	n/a	17%	2%
Total	-9%	-14%	n/a	-45%	-9%	-5%	0%

Approximately 4,000 ha of dairy, 5,000 ha of dairy support, and 2,500 ha of arable land are estimated to switch mostly to sheep and beef as it is more profitable to switch land use than adopt land management options or trade NDAs to achieve the allocated N limit. Forestry and horticulture enterprises also expand by a few hundred hectares. The scenario would also incentivise landowners to adopt a mix of mitigation practices (Figure 36). Estimates indicate that dairy support, arable, and sheep and beef farmers adjust their management and then sell their excess allowances to dairy farmers in the catchment (Figure 37). This allocation option also provides a higher NDA to forestland owners relative to the grandparenting option. Forestry has an average leaching rate of less than 1.0 kgN/ha, so landowners benefit from the ability to sell most of the NDAs that they are allocated.

Figure 36: Proportion of farm practices, nutrient vulnerability cap and trade scenario

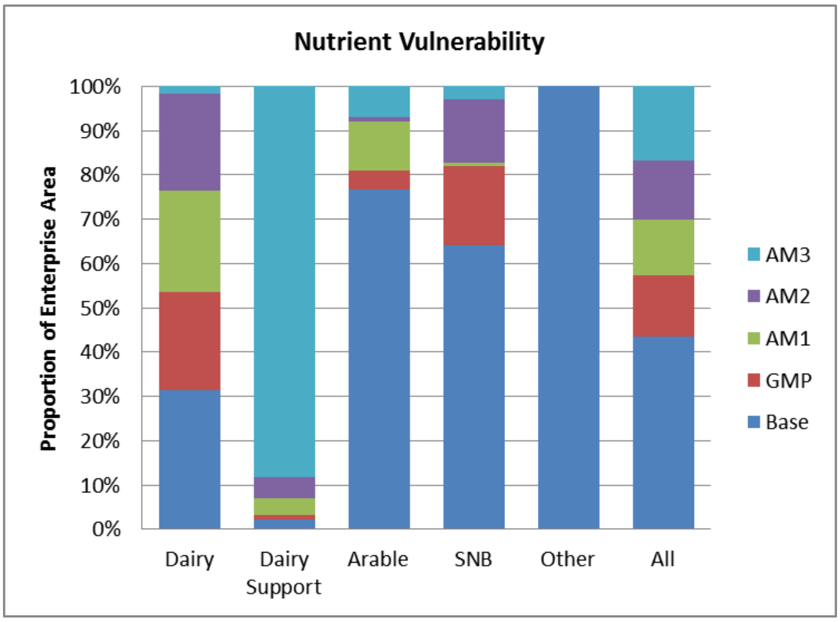
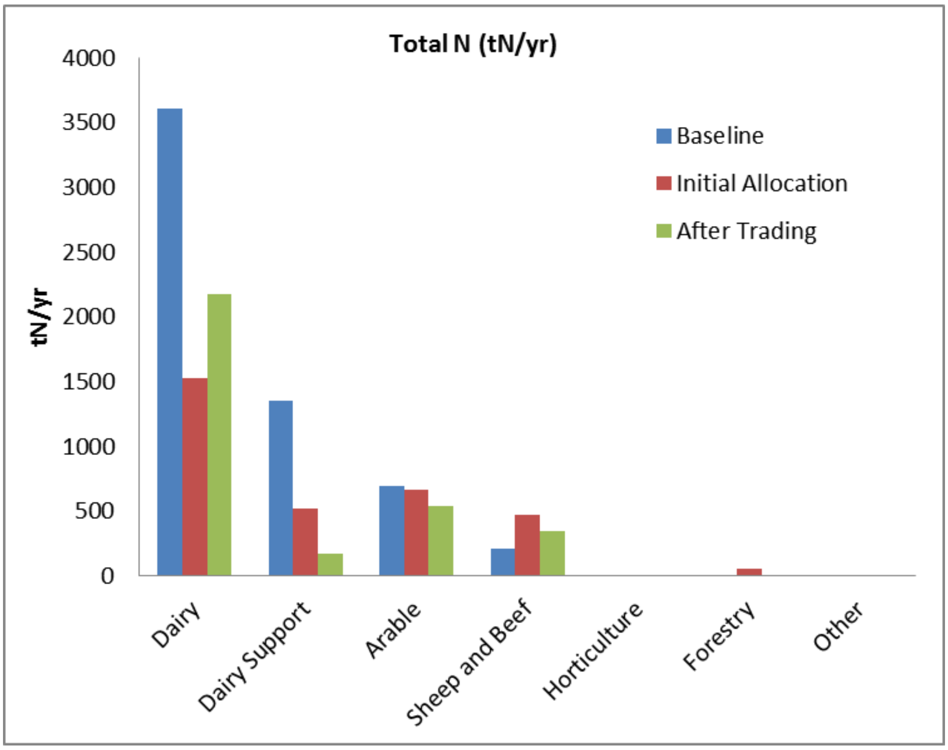
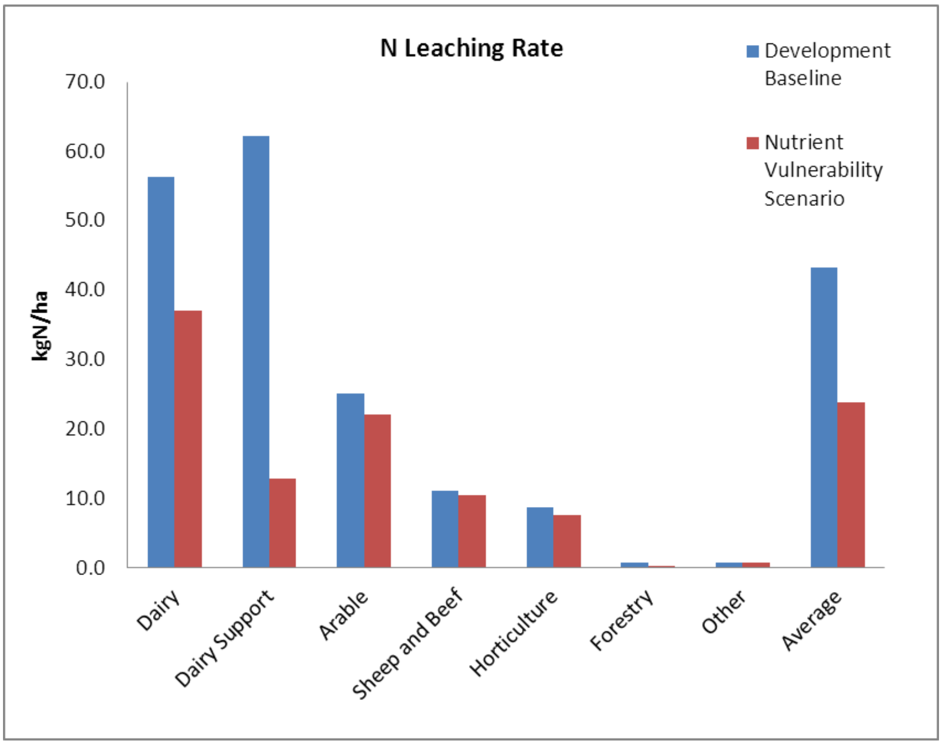


Figure 37: N leaching and allocation (tN/yr) by enterprise, nutrient vulnerability cap and trade scenario



The scenario reduces the overall N leaching rate in the catchment (Figure 38) from 43.3 kg/ha to 23.9 kg/ha. A majority of these reductions expected to come from dairy and dairy support.

Figure 38: N leaching rate (kgN/ha) by enterprise, nutrient vulnerability cap and trade scenario



All land based production outputs with the exception of meat and timber and pulp reduce by between 12% and 30% under this policy scenario (Table 26).

Table 26: Farm-level production, nutrient vulnerability, cap and trade scenario

Product	Units	Baseline	Policy Scenario	% Change
Milk Solids	Tonnes	95,037	80,761	-15%
Animals	thousand head	131	109	-17%
Meat	Tonnes	28,844	28,921	0%
Wool	Tonnes	521	461	-12%
Fruit	Tonnes	2,709	1,988	-27%
Wheat and Barley	Tonnes	130,182	101,527	-22%
Silage	Tonnes	58,926	41,154	-30%
Vegetables	Tonnes	61,023	53,230	-13%
Seeds	Tonnes	11,151	7,770	-30%
Straw	thousand bales	170	124	-27%
Timber and Pulp	thousand m3	27	32	18%

Auction-based Allocation of Nutrient Discharge Allowances

This scenario capped N and used an auction mechanism to sell the 3,240 tN/yr of N to landowners, thus the average landowner would have a target of 23.9 kgN/ha. Landowners must purchase an allowance for every unit of nitrogen they discharge. Allowances are purchased by those who value them the most. Farmers, in an auction, will theoretically bid up to their marginal cost of mitigation for an allowance. The estimates for this scenario will be similar to those found in the catchment-wide cap and trade policy scenarios with free allocation, with the exception of the impacts on net revenue, cash farm surplus, and council revenue. This is because the free allocation approach gives an initial allocation of NDAs to landowners at no charge, while NDAs are purchased in an auction.

A NDA price of $22.20/kg was estimated to be necessary to reduce total N leaching to reach the 45% reduction target. This is approximately the same value as the marginal cost of purchasing an NDA in the other policy scenarios that had catchment-wide trading (ie, grandparenting and nutrient vulnerability) but free allocation. Again, the key difference with the auctioned allowance scenario is that the NDA is being purchased from the council rather than another landowner.

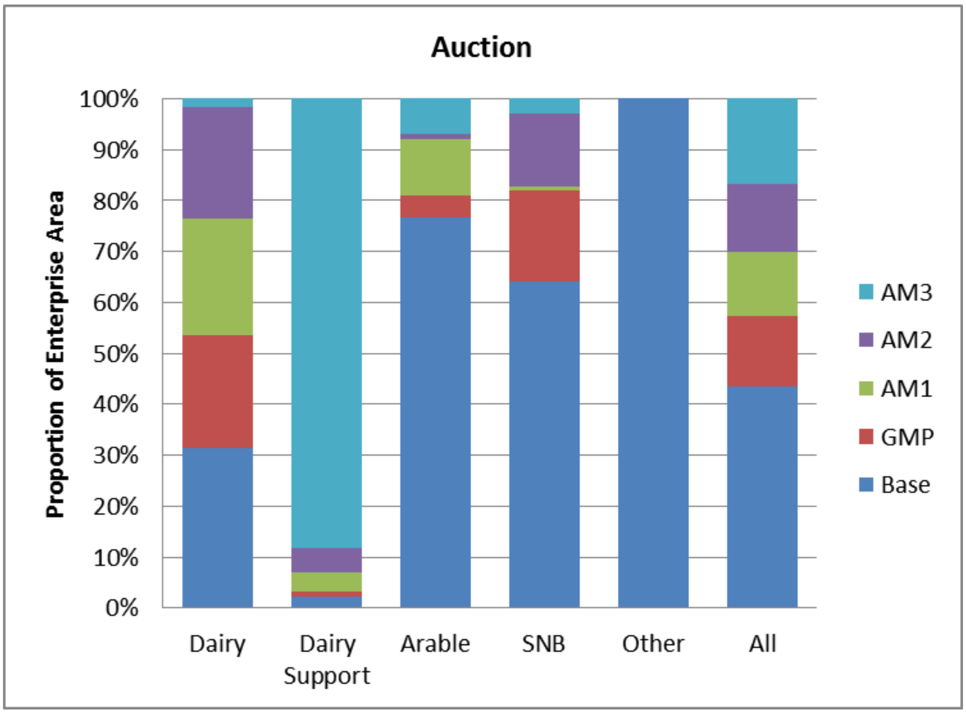
A summary of the changes in key outputs relative to the baseline is listed in Table 27. Results indicated that total net revenue could decrease by 31% across the catchment. The average abatement cost under this scenario is $40/kgN, which includes both the costs of mitigation and the price of the NDA. Total cash farm surplus decreases by 106%, resulting in a negative cash farm surplus figure for the catchment. A significant proportion of these reductions results from the purchase of NDAs. This gave $72 million/yr in auction revenue to the council for the Hinds catchment when the policy is fully implemented. This revenue can be used in a variety of ways, such as reducing rates, paying for additional mitigation, or investing in other improvements to the community. It could also be returned to landowners to help offset the cost of purchasing NDAs and carrying out the mitigation required to achieve the nitrogen reduction goal. If all auction revenue was refunded back to the farmers, then total net revenue and cash farm surplus for the catchment would be similar to the estimates from the grandparenting allocation with trading policy scenario, about a 10% and 15% decrease, respectively. Total P loss and GHG emissions are reduced by 13% and 11%, respectively, indicating that an auction based allocation scenario could result in other environmental co-benefits.

Table 27: Key outputs, auction-based allocation scenario

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$178.6	-$0.02	$48.3	2,173	44	611,452	58.0
Dairy Support	$11.9	-$4.11	$5.9	267	3	11,304	22.0
Arable	$29.1	-$1.41	$11.9	536	8	21,280	24.4
Sheep & Beef	$6.8	-$1.77	$5.7	256	25	110,539	26.3
Horticulture	$4.7	$2.29	$0.1	4	0	1,113	0.5
Forestry	$2.0	$0.52	$0.1	3	0	-49,745	3.2
Other	$0.1	$0.02	$0.0	1	0	297	0.9
Total	$233.3	-$4.5	$72.1	3,240	80	706,240	135.4
Percent Change From Baseline							
Dairy	-29%	-100%	n/a	-40%	-10%	-13%	-10%
Dairy Support	-52%	-158%	n/a	-80%	-74%	-22%	2%
Arable	-39%	-111%	n/a	-22%	-23%	-15%	-11%
Sheep & Beef	-27%	-160%	n/a	22%	14%	35%	40%
Horticulture	30%	27%	n/a	45%	n/a	33%	33%
Forestry	59%	47%	n/a	60%	n/a	60%	61%
Other	6%	-36%	n/a	27%	n/a	25%	1%
Total	-31%	-106%	n/a	-45%	-13%	-11%	0%

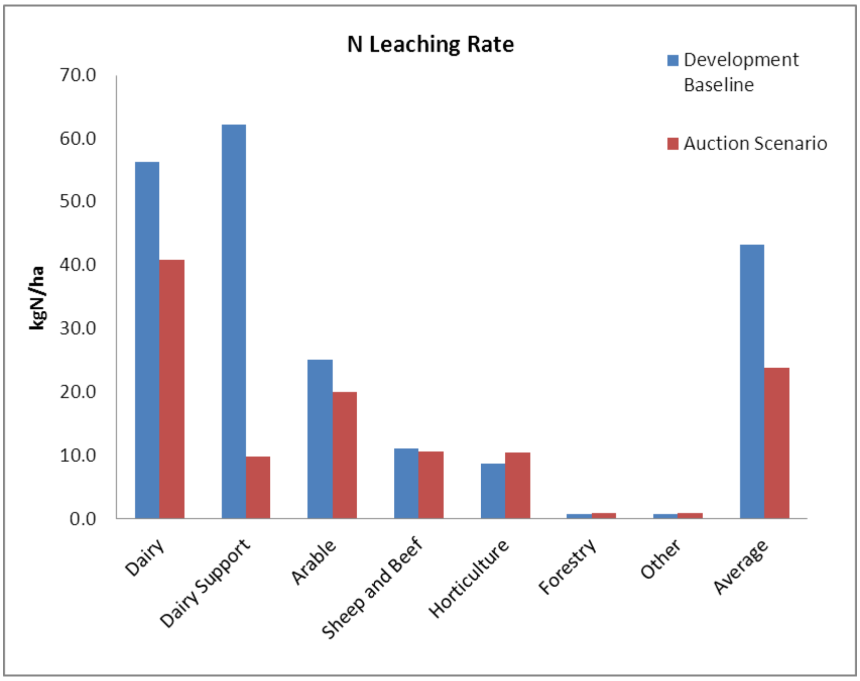
This scenario results in about 6,000 ha of dairy and 3,000 ha of arable land to change use. Most of this change is to sheep and beef, although forestry, horticulture, and dairy support all expand by a few hundred hectares as well. These land use changes occur as it is more profitable to switch land use than to adopt land management options or buy NDAs in an auction to achieve the allocated N limit. The scenario also incentivises farmers to switch from baseline practices to a mix of new mitigation practices. Estimates indicate that almost all dairy support farmers adjust their management to AM3 (Figure 39).

Figure 39: Proportion of farm practices by enterprise, auction-based allocation scenario



The scenario reduces the overall N leaching rate in the catchment (Figure 40) from 43.3 kg/ha to 23.9 kg/ha. These reductions are expected to come from a mix of pastoral and arable enterprises, with dairy support experiencing the greatest reduction through management change.

Figure 40: N leaching rate (kgN/ha) by enterprise, auction-based allocation scenario



Most arable and dairy-related output decreases by 9% or more (Table 28) as a result of changes in land management and land use. Meat, wool, fruit, and forestry products are estimated to increase between 3 and 64% as the area of these enterprises increase in this scenario.

Table 28: Farm-level production, auction-based allocation scenario

Product	Units	Baseline	Policy Scenario	% Change from Baseline
Milk Solids	tonnes	95,037	86,663	-9%
Animals	thousand head	131	119	-9%
Meat	tonnes	28,844	31,063	8%
Wool	tonnes	521	536	3%
Fruit	tonnes	2,709	3,607	33%
Wheat and Barley	tonnes	130,182	108,469	-17%
Silage	tonnes	58,926	47,066	-20%
Vegetables	tonnes	61,023	52,921	-13%
Seeds	tonnes	11,151	9,598	-14%
Straw	thousand bales	170	148	-13%
Timber and Pulp	thousand m3	27	45	64%

Grandparenting Cap with Trading Programme and Resource Rental Charge

This scenario used a grandparenting allocation approach to allocate the 3,240tN/yr to landowners. Trading allowed NDAs to be traded between farmers in all areas of the catchment and a resource rental charge of $2.50/kgN that was imposed on all N leached in the catchment. The resource rental will provide funds for the council to administer the programme and potentially undertake larger mitigation options within the catchment. The resource rental also provides an additional incentive for landowners to reduce their total N leaching in the catchment. Note that the rate of $2.50 is illustrative. The council may wish to charge a lower or higher rate or give a portion of the funds back to the landowners in some form. If the entire amount collected was refunded, then total net revenue and cash farm surplus for the catchment would be similar to those estimated under the grandparenting allocation with trading but no resource rental payment. A summary of the changes in key outputs relative to the baseline is listed in Table 29. The land use and management change estimates from this scenario are very close to the estimates for the grandparenting cap and trade programme *without* a resource rental charge.

Results indicated that total net revenue could decrease by 12% while total cash farm surplus decreases by 25%. A significant proportion of these reductions come from the resource rental charge, totalling about $8.1 million for the Hinds catchment. Achieving the 45% N reduction target under this scenario comes at an average abatement cost of $15.60/kgN. Total P loss and GHG emissions were also reduced by 13% and 11%, respectively indicating that a cap and trade programme with grandparenting allocation and a resource rental for N leaching has potential environmental co-benefits.

Table 29: Key outputs, grandparenting cap and trade plus resource rental scenario

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$221.5	$42.87	$5.4	2,173	44	611,452	58.0
Dairy Support	$17.2	$1.16	$0.7	267	3	11,304	22.0
Arable	$39.7	$9.17	$1.3	536	8	21,280	24.4
Sheep & Beef	$11.8	$3.29	$0.6	256	25	110,539	26.3
Horticulture	$4.8	$2.38	$0.0	4		1,113	0.5
Forestry	$2.1	$0.57	$0.0	3		- 49,745	3.2
Other	$0.1	$0.04	$0.0	1		297	0.9
Total	$297.2	$59.5	$8.1	3,240	80	706,240	135.4
Percent Change From Baseline							
Dairy	-12%	-22%	n/a	-40%	-10%	-13%	-10%
Dairy Support	-31%	-84%	n/a	-80%	-74%	-22%	2%
Arable	-17%	-26%	n/a	-22%	-23%	-15%	-11%
Sheep & Beef	27%	12%	n/a	22%	14%	35%	40%
Horticulture	32%	32%	n/a	45%	n/a	33%	33%
Forestry	63%	62%	n/a	60%	n/a	60%	61%
Other	23%	18%	n/a	27%	n/a	25%	1%
Total	-12%	-25%	n/a	-45%	-13%	-11%	0%

About 6,000 ha of dairy and 3,000 ha of arable land are estimated to mostly switch to sheep and beef, although forestry, horticulture and dairy support all expand by a few hundred hectares. These land use changes occur as it is more profitable to switch land use than to adopt land management options or trade NDAs to achieve the allocated N limit. The scenario incentivises landowners to adopt a mix of GMP, or advanced mitigation (Figure 41). Estimates indicate that majority of dairy support farmers adjust their management to AM3 and then sell their excess allowances to other pastoral and arable farmers in the catchment (Figure 42).

Figure 41: Proportion of farm practices by enterprise, grandparenting cap and trade plus resource rental scenario

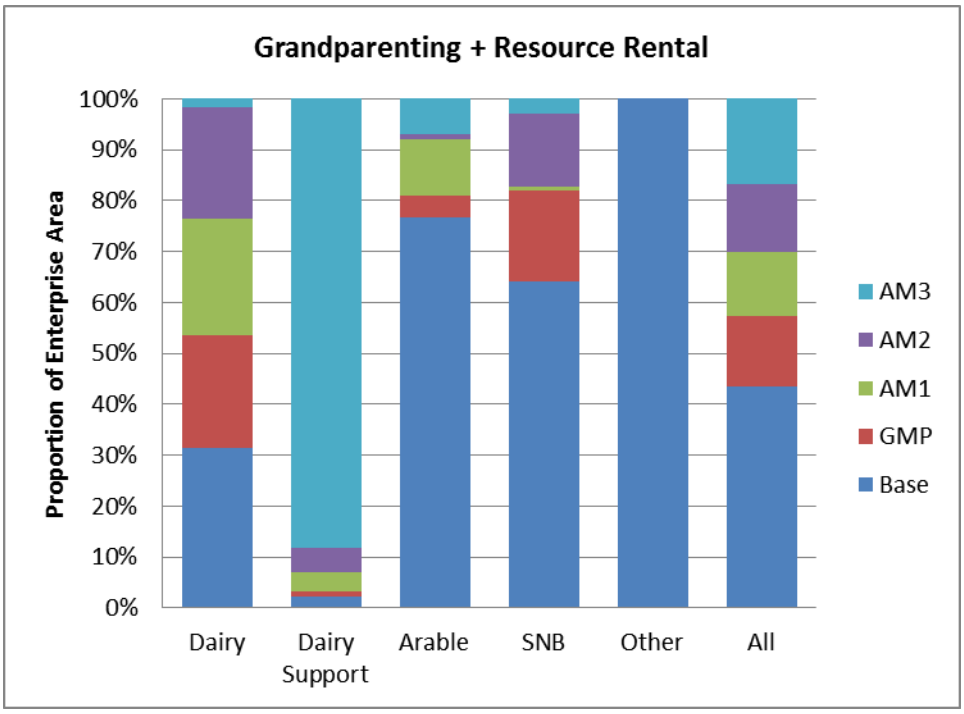
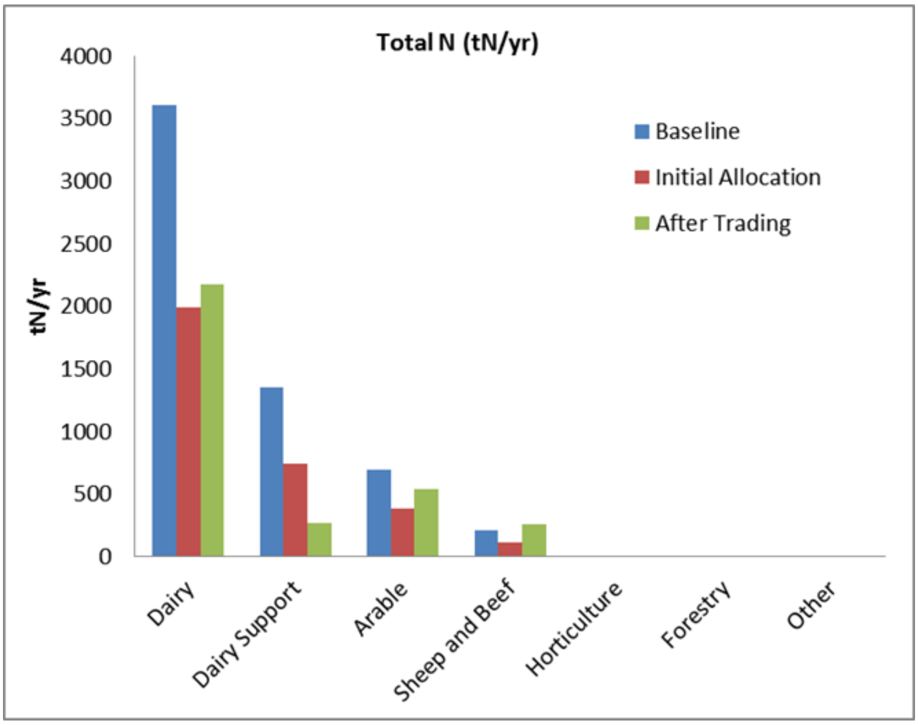
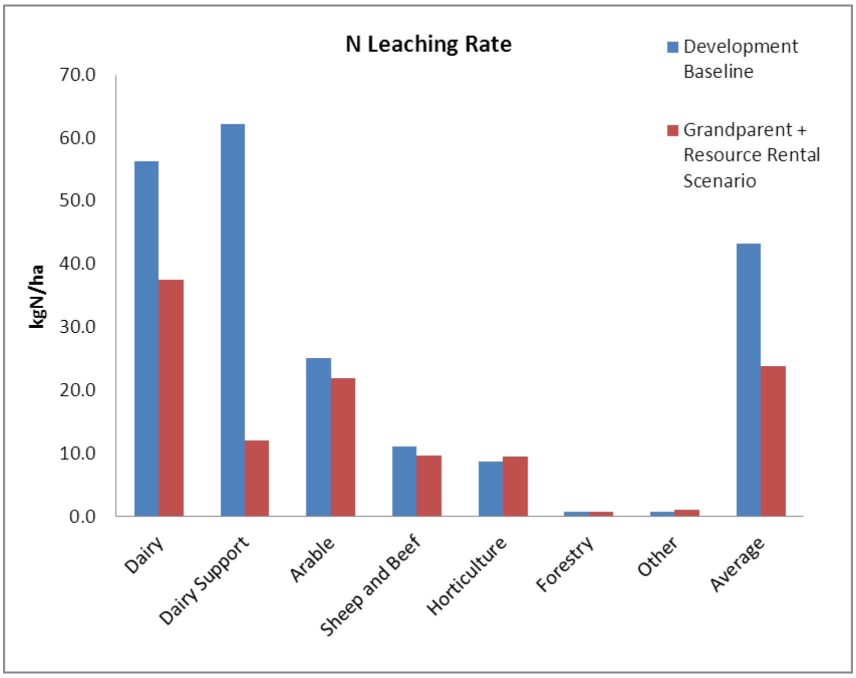


Figure 42: N leaching and allocation (tN/yr) by enterprise, grandparenting cap and trade plus resource rental scenario



The scenario also reduces the overall N leaching rate in the catchment significantly (Figure 43), from 43.3 kg/ha to 23.9 kg/ha. These reductions are expected to come from a mix of pastoral and arable enterprises, with dairy support experiencing the greatest reduction through management change.

Figure 43: N leaching rate (kgN/ha) by enterprise, grandparent cap, and trade plus resource rental scenario



Most arable and dairy-related output decreases by 9% or more (Table 30) as a result of changes in management and land use. Sheep, beef, fruit, and forestry products are estimated to increase between 3 and 64% as the area of these enterprises expand in this scenario.

Table 30: Farm-level production, grandparent cap and trade plus resource rental scenario

Product	Units	Baseline	Policy Scenario	% Change
Milk Solids	tonnes	95,037	86,663	-9%
Animals	thousand head	131	119	-9%
Meat	tonnes	28,844	31,063	8%
Wool	tonnes	521	536	3%
Fruit	tonnes	2,709	3,607	33%
Wheat and Barley	tonnes	130,182	108,469	-17%
Silage	tonnes	58,926	47,066	-20%
Vegetables	tonnes	61,023	52,921	-13%
Seeds	tonnes	11,151	9,598	-14%
Straw	thousand bales	170	148	-13%
Timber and Pulp	thousand m3	27	45	64%

Equal allocation Cap and Trading Programme

This scenario used Nutrient Management Zones (NMZ) to allocate the 3,240 tN/yr to landowners. The 3 NMZ were LPL, HPL, and NPL (see Chapter 3 for more details on this allocation approach). Table 31 shows how the NDAs were allocated across the different zones in this scenario. Over 95% of the land in the catchment fell into the HPL zone and was subsequently allocated a total of 3176 tN/yr. Landowners in the LPL and NPL zones were allocated a total of 63 and 2 tN/yr, respectively. This scenario also included trading where all landowners were allowed to trade their NDAs within their own NZFARM zone. A summary of the changes in key outputs relative to the baseline is listed in Table 32.

Table 31: Discharge allowances based on equal allocation scenario

NZFARM Zone	Area ('000 ha)	Total N Leaching (tN/yr)		N Leaching Rate (kgN/ha)	
		Baseline	Policy Scenario Allocation	Baseline	Policy Scenario NDA
Low Productive Land (LPL)	6.4	63	63	9.8	9.8
High Productive Land (HPL)	128.3	5,796	3,176	45.2	24.8
No Productive Land (NPL)	0.8	2	2	2.0	2.0
Total	135.4	5,860	3,240	43.3	23.9

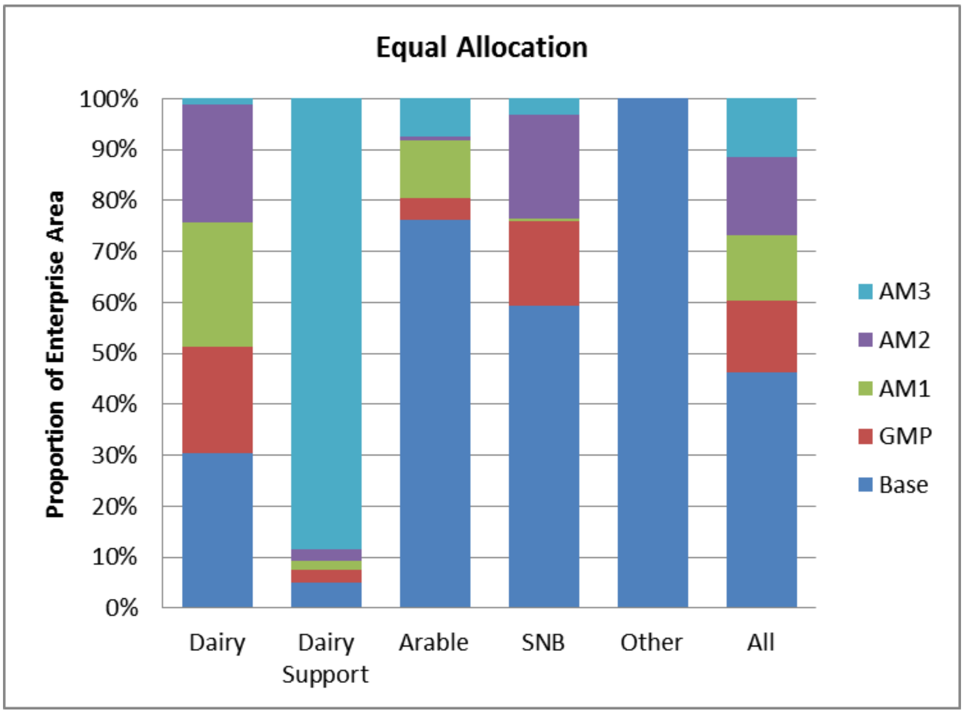
Results indicated that total net revenue could decrease by 9% while total cash farm surplus decreases by about 12%. Thus achieving the 45% N reduction target comes at an average abatement cost of $11.10/kgN. Total P loss and GHG emissions were both reduced by 9% indicating that there are potential environmental co-benefits.

Table 32: Key outputs, equal allocation scenario

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$232.0	$49.47	$0.0	2,156	45	622,961	58.6
Dairy Support	$11.3	$1.26	$0.0	178	2	7,115	13.6
Arable	$41.8	$10.71	$0.0	556	8	21,515	24.4
Sheep & Beef	$15.4	$4.64	$0.0	341	29	138,607	32.6
Horticulture	$5.3	$2.65	$0.0	5	0	1,237	0.5
Forestry	$3.0	$0.82	$0.0	4	0	- 70,425	4.6
Other	$0.1	$0.04	$0.0	1	0	299	1.1
Total	$308.8	$69.6	$0.0	3,240	84	721,309	135.4
Percent Change From Baseline							
Dairy	-8%	-10%	n/a	-40%	-8%	-11%	-8%
Dairy Support	-55%	-82%	n/a	-87%	-83%	-51%	-37%
Arable	-12%	-14%	n/a	-19%	-25%	-14%	-11%
Sheep & Beef	65%	57%	n/a	63%	33%	69%	73%
Horticulture	47%	48%	n/a	53%	n/a	48%	47%
Forestry	134%	134%	n/a	126%	n/a	126%	128%
Other	25%	26%	n/a	29%	n/a	26%	18%
Total	-9%	-12%	n/a	-45%	-9%	-9%	0%

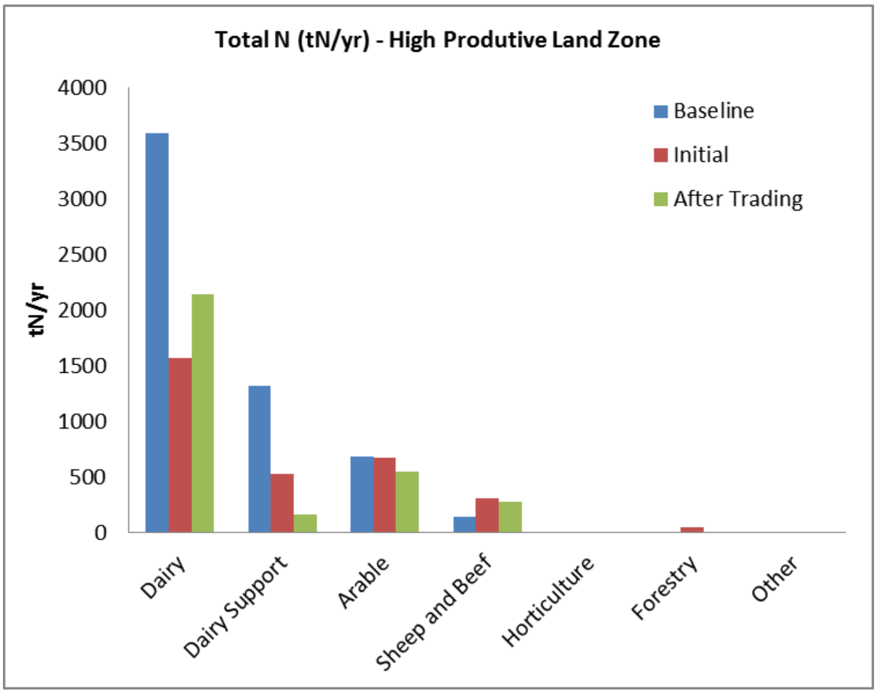
Approximately 5,000 ha each of dairy and dairy support land is estimated to switch to sheep and beef farming as it is more profitable to switch land use than to adopt land management options or trade NDAs to achieve the allocated N limit. Many landowners find it advantageous to adopt GMP or advanced mitigation practices than to switch land use. Most of the land that stays in dairy support farmers adopts AM3 practices (Figure 44).

Figure 44: Proportion of farm practices by enterprise, equal allocation scenario



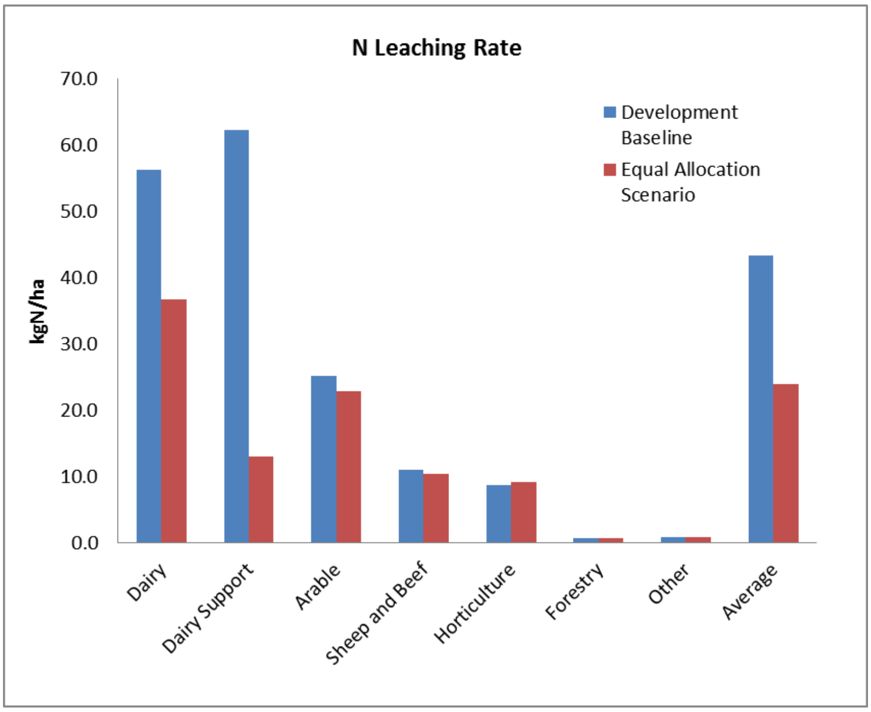
Dairy farmers are estimated to purchase allowances from dairy support, sheep and beef and arable, and forestry landowners. This trading primarily occurs in the HPL zone as it covers 95% of the catchment (Figure 45).

Figure 45: N leaching and allocation (tN/yr) by enterprise, equal allocation scenario, HPL zone



The scenario reduces the overall N leaching rate in the catchment (Figure 46), from 43.3 kg/ha to 23.9 kg/ha. These reductions are expected to come from dairy, dairy support and arable enterprises through the improvements to land management.

Figure 46: N leaching rate (kgN/ha) by enterprise, equal allocation scenario



Meat and wool outputs are estimated to increase with sheep and beef land increase, while milk solids, animal, and arable related outputs decrease (Table 30). Fruit and forest products also increase significantly due to increase in land area.

Table 33: Farm-level production, equal allocation scenario

Product	Units	Baseline	Policy Scenario	% Change from Baseline
Milk Solids	tonnes	95,037	88,778	-7%
Animals	thousand head	131	121	-7%
Meat	tonnes	28,844	35,430	23%
Wool	tonnes	521	584	12%
Fruit	tonnes	2,709	4,009	48%
Wheat and Barley	tonnes	130,182	101,227	-22%
Silage	tonnes	58,926	40,359	-32%
Vegetables	tonnes	61,023	56,259	-8%
Seeds	tonnes	11,151	9,794	-12%
Straw	thousand bales	170	151	-11%
Timber and Pulp	thousand m3	27	64	134%

Catchment Club Cap and Trading Programme

This scenario allocated the 3,240tN/yr to NZFARM zones (‘clubs’). These clubs were based on the land included in the two irrigation schemes: Mayfield Hinds, Valetta. Land outside the irrigation schemes were not considered part of any club. Table 34 shows how the NDAs were allocated across the different zones. Landowners in the Mayfield-Hinds and Valetta zones were allocated a total of about 1560 and 458 tN/yr, respectively, based on a grandparenting allocation approach. Trading was only allowed between landowners within each of the two irrigation scheme ‘clubs’. Farmers managing land outside the ‘club’ were given a total of about 1223 tN/yr based on an average allocation approach, which was an equivalent of 15.8kgN/ha. However, those landowners were not allowed to trade their NDAs. A summary of the changes in key outputs relative to the baseline is listed in Table 35.

Table 34: Discharge allowances based on catchment club scenario

NZFARM Zone	Area (‘000 ha)	Total N Leaching (tN/yr)		N Leaching Rate (kgN/ha)	
		Baseline	Policy Scenario Allocation	Baseline	Policy Scenario NDA
Mayfield Hinds	43.4	2820	1559	65.0	35.9
Valetta	14.6	827	457	56.5	31.2
Other	77.4	2213	1224	28.6	15.8
Entire Catchment	135.4	5860	3240	43.3	23.9

Results indicated that total net revenue could decrease by 12% while total cash farm surplus decreases by about 18% under the catchment club cap and trade programme. These costs primarily result from the average allocation approach used outside the 2 irrigation scheme clubs and then not allowing trading outside the irrigation clubs. This scenario also incentivises changes in land use and land management practices such that total N leaching is reduced by 46%. These reductions come at an average abatement cost of $14.30/kgN. Total P loss and GHG emissions were reduced by 18% and 14%, respectively, indicating that a catchment club cap and trade programme potentially have environmental co-benefits.

Table 35: Key outputs, catchment club scenario

Enterprise	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Enterprise Area ('000 ha)
Estimated Values							
Dairy	$218.1	$45.76	$0.0	2,047	42	587,791	56.1
Dairy Support	$22.1	$2.57	$0.0	357	4	13,757	26.6
Arable	$40.3	$10.22	$0.0	494	7	20,838	24.4
Sheep & Beef	$11.1	$3.44	$0.0	229	22	99,834	23.8
Horticulture	$5.3	$2.64	$0.0	5	0	1,231	0.5
Forestry	$1.9	$0.53	$0.0	2	0	- 45,807	3.0
Other	$0.2	$0.06	$0.0	1	0	390	1.0
Total	$299.0	$65.2	$0.0	3,135	76	678,034	135.4
Percent Change From Baseline							
Dairy	-13%	-16%	n/a	-43%	-14%	-16%	-12%
Dairy Support	-12%	-64%	n/a	-73%	-62%	-5%	23%
Arable	-15%	-18%	n/a	-29%	-30%	-17%	-11%
Sheep & Beef	19%	17%	n/a	9%	2%	22%	26%
Horticulture	47%	47%	n/a	59%	n/a	47%	47%
Forestry	51%	51%	n/a	49%	n/a	47%	48%
Other	64%	64%	n/a	77%	n/a	64%	5%
Total	-12%	-18%	n/a	-46%	-18%	-14%	0%

While some landowners continue with their baseline practices at the catchment level, many landowners find it advantageous to adopt GMPs or advanced mitigation practices, particularly dairy and dairy support farmers (Figure 47). Landowners in both irrigation scheme 'clubs' can also improve management to mitigate N leaching beyond their allocated level and sell excess allowances to others in their particular 'club' (Figure 48a–b). A key difference in the catchment club scenario relative to some of the other scenarios with catchment-wide trading is that there is minimal area of sheep and beef farming in the two irrigation schemes. Dairy and arable enterprises are then estimated to purchase allowances from dairy support farmers.

Figure 47: Proportion of farm practices by enterprise, catchment club scenario

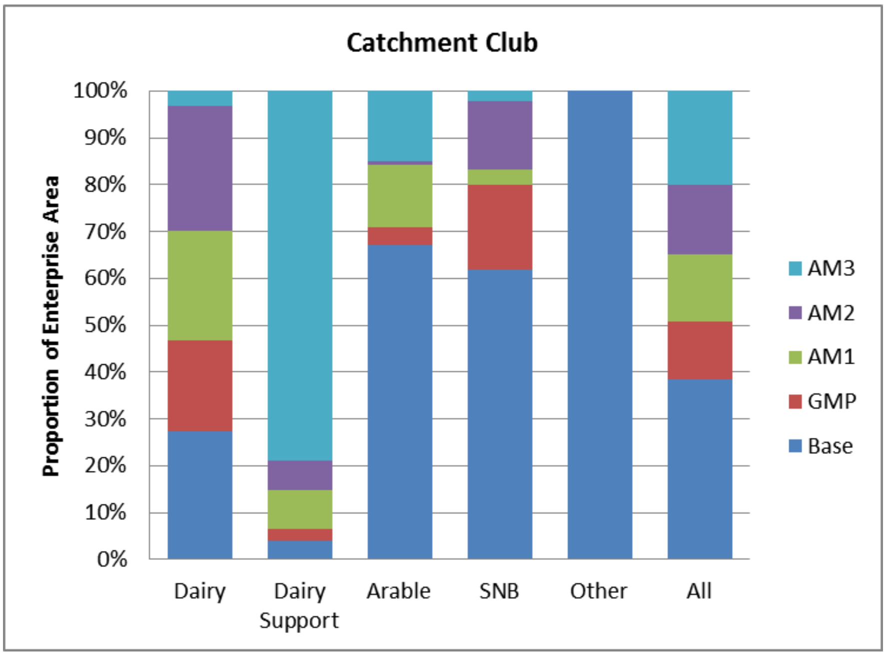
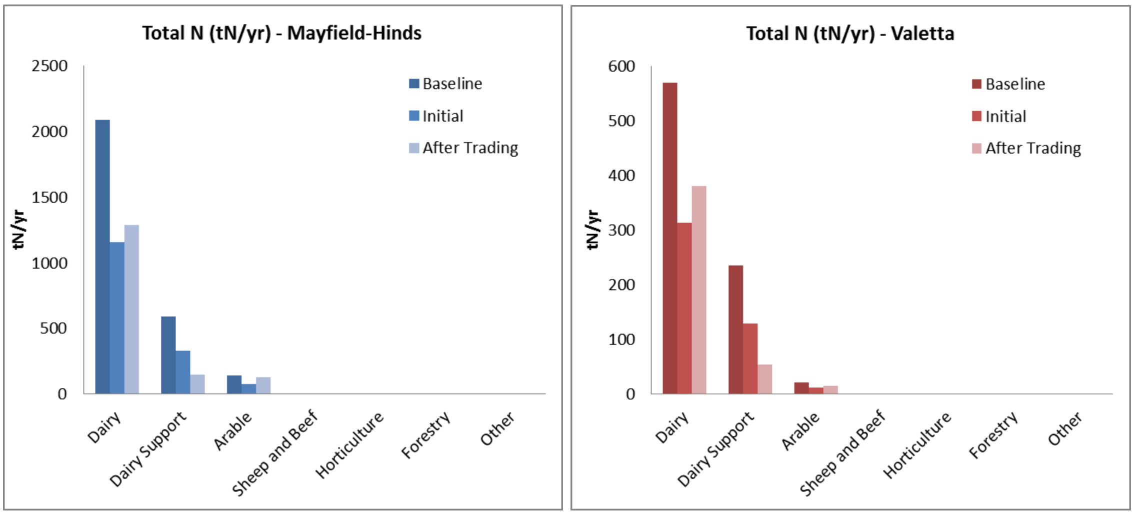
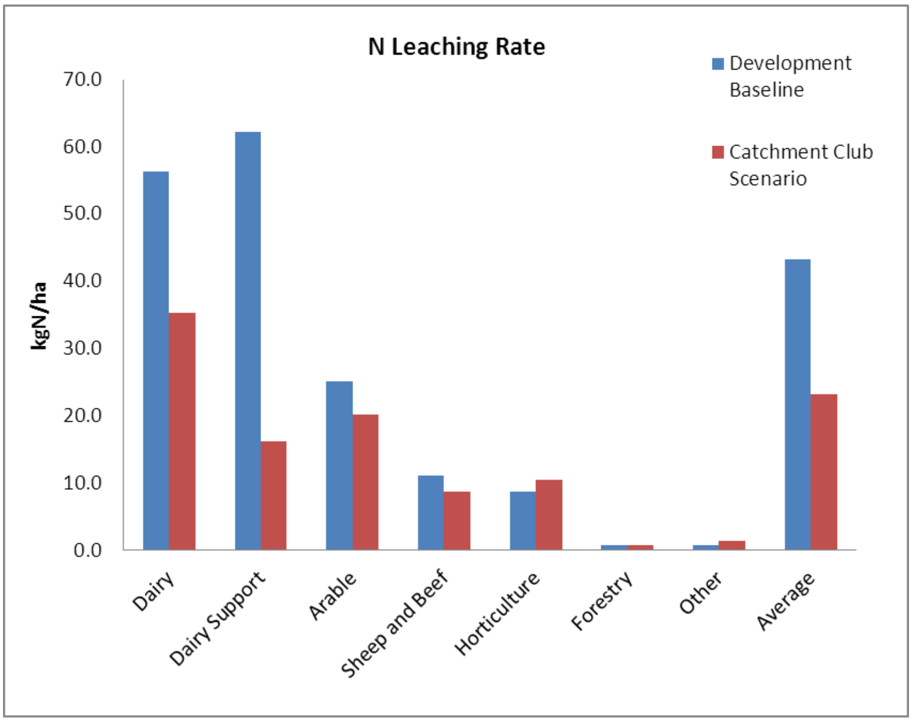


Figure 48 a–b: N leaching and allocation (tN/yr) by enterprise for Mayfield-Hinds (a) and Valetta (b) catchment clubs only, catchment club scenario



The scenario reduces the overall N leaching rate in the catchment (Figure 49) from 43.3 kg/ha to 23.2 kg/ha. These reductions are expected to come from a mix of pastoral and arable enterprises in the catchment.

Figure 49: N leaching rate (kgN/ha) by enterprise, catchment club scenario



Pastoral and arable outputs decrease in this scenario, with the exception of meat, which increases by about 2% (Table 36). Fruit and forest production grows as the area of these enterprises increase.

Table 36: Farm-level production, catchment club scenario

Product	Units	Baseline	Policy Scenario	% Change from Baseline
Milk Solids	tonnes	95,037	83,242	-12%
Animals	thousand head	131	114	-13%
Meat	tonnes	28,844	29,310	2%
Wool	tonnes	521	504	-3%
Fruit	tonnes	2,709	3,987	47%
Wheat and Barley	tonnes	130,182	113.692	-13%
Silage	tonnes	58,926	51,179	-13%
Vegetables	tonnes	61,023	45,399	-26%
Seeds	tonnes	11,151	9,494	-15%
Straw	thousand bales	170	149	-12%
Timber and Pulp	thousand m3	27	41	51%

Comparison of Policy Scenario Results

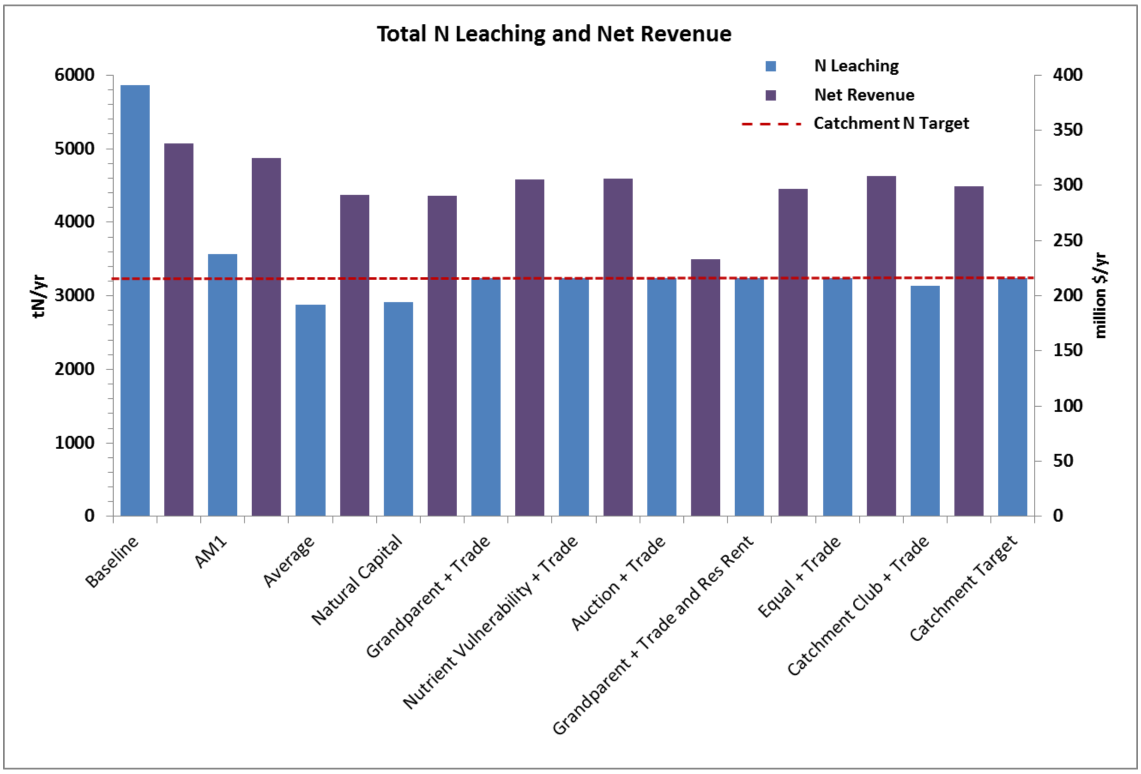
For each policy scenario, the mitigation costs of achieving the nutrient reduction target and the resulting changes in net farm revenue, cash farm surplus, council revenue, N leaching, P loss, GHG emissions, and the average cost of N abatement are tracked. A summary of the key outputs for each policy scenario are listed in Table 37.

Table 37: NZFARM Policy Analysis Summary, Hinds Catchment

Policy Scenario	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Annual Estimated Values							
Baseline (no policy)	$338.0	$79.4	$0.0	5,860	92	791,631	$0.00
Advanced Mitigation 1	$324.9	$70.7	$0.0	3,570	81	709,995	$5.70
Average Allocation	$291.8	$63.3	$0.0	2,881	79	652,004	$15.50
Natural Capital Allocation	$291.0	$61.9	$0.0	2,912	78	669,373	$15.90
Grandparent Allocation + Trading	$305.3	$67.6	$0.0	3,240	80	706,240	$12.50
Nutrient Vulnerability Allocation + Trading	$306.0	$68.5	$0.0	3,240	84	752,187	$12.20
Auction Allocation + Trading	$233.3	-$4.5	$72.1	3,240	80	706,209	$40.00
Grandparent Allocation + Resource Rent	$297.2	$59.5	$8.1	3,240	80	706,240	$15.60
Equal Allocation + Trading	$308.8	$69.6	$0.0	3,240	84	721,309	$11.10
Catchment Club Allocation + Trading	$299.0	$65.2	$0.0	3,135	76	678,034	$14.30
Percent Change From Baseline							
Advanced Mitigation 1	-4%	-11%	n/a	-39%	-12%	-10%	n/a
Average Allocation	-14%	-20%	n/a	-51%	-14%	-18%	n/a
Natural Capital Allocation	-14%	-22%	n/a	-50%	-16%	-15%	n/a
Grandparent Allocation + Trading	-10%	-15%	n/a	-45%	-13%	-11%	n/a
Nutrient Vulnerability Allocation + Trading	-9%	-14%	n/a	-45%	-9%	-5%	n/a
Auction Allocation + Trading	-31%	-106%	n/a	-45%	-13%	-11%	n/a
Grandparent Allocation + Resource Rent	-12%	-25%	n/a	-45%	-13%	-11%	n/a
Equal Allocation + Trading	-9%	-12%	n/a	-45%	-9%	-9%	n/a
Catchment Club Allocation + Trading	-12%	-18%	n/a	-46%	-18%	-14%	n/a

Figure 50 compares the amount of total N (kg/yr) and net farm revenue (million $/yr) across the policy scenarios. The 45% N leaching reduction target is relatively high, but most policy scenarios do meet the target. However, all scenarios modelled also experience a decrease in net catchment revenue.

Figure 50: Total N leaching (tN/yr) and net farm revenue (million $/yr) from each policy scenario



The modelled scenarios also have a varying impact on the enterprise-level net farm revenues, as shown in Figure 51 and Figure 52.

Figure 51: Net farm revenue by enterprise for each policy scenario

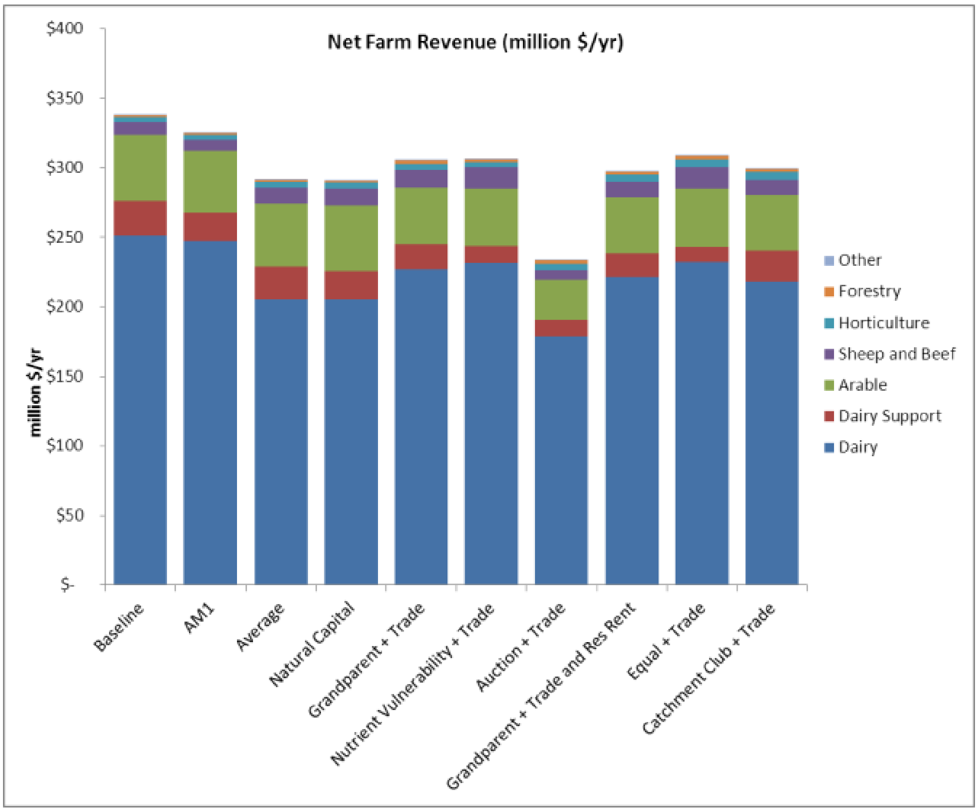
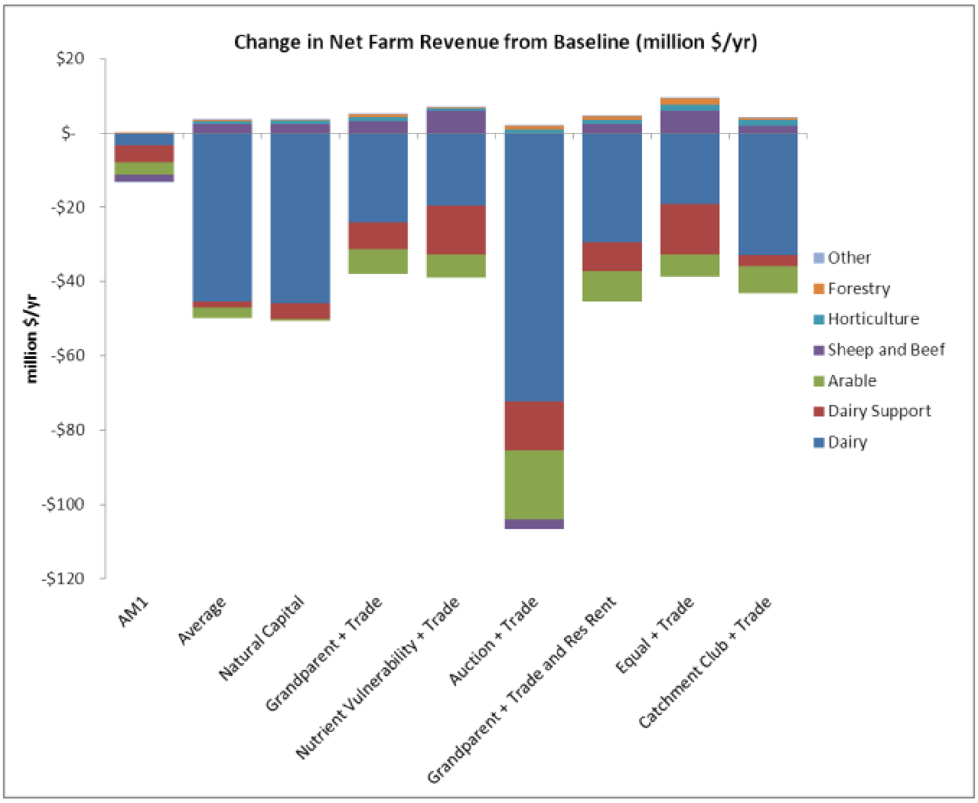
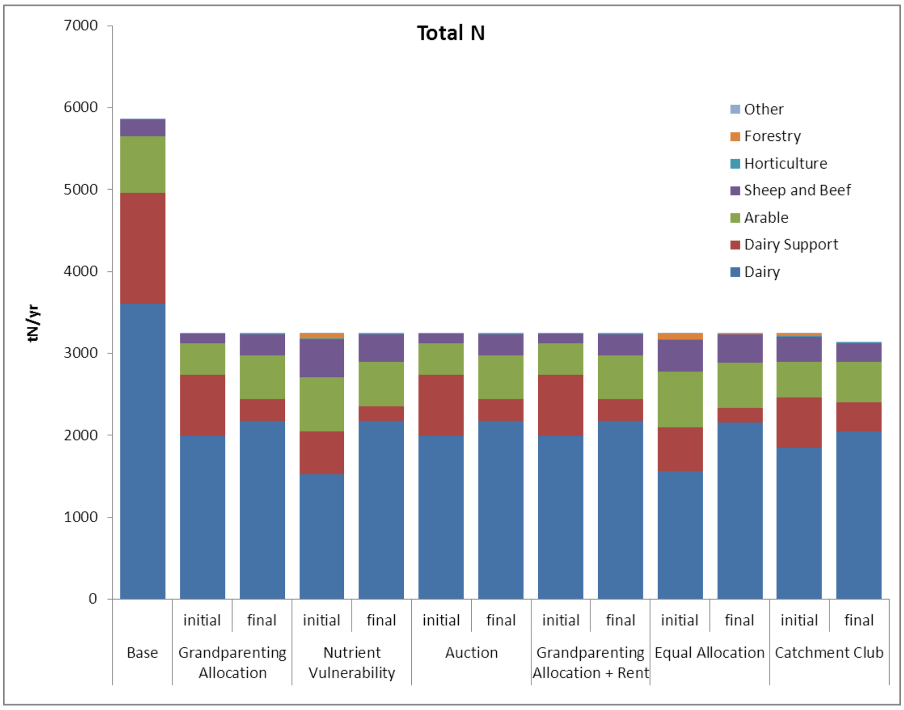


Figure 52: Change in net farm revenue from the baseline by enterprise for each policy scenario



Where trading was allowed the distribution of N leaching between the enterprises changed depending on the scenario, as highlighted in Figure 53.

Figure 53: Initial N allocation and final N leaching (tN/yr) for the scenarios with trading



The key findings for each set of policy scenarios is summarised here. More details can be found in the discussion and conclusions (section 6 of the report).

Improving land management practices

The policy scenario to estimate the impacts of improving management practices assumed that all pastoral and arable landowners must implement the entire set of practices listed in the advanced mitigation 1 scenario. This resulted in a 39% reduction in total N leaching with a 4% loss in net revenue. As the 45% N reduction target is not met, additional policy instruments would be required to achieve the remaining reductions.

Farm specific caps

Farm specific caps involve a catchment-wide cap to be established and then allocating this cap amongst landowners. Two allocation options were modelled for this set of scenarios: averaging and natural capital. Both the averaging and natural capital allocation approaches were estimated to reduce net revenue by 14%. These two approaches achieved a 51% and 50%, respectively, decrease in N leaching in the catchment. As landowners are not able to trade any excess NDAs more reductions are achieved than required. Under averaging, more intensive landowners, such as dairy and dairy support, on the high leaching soils face higher costs than those on low leaching soils. Those dairy and dairy support enterprises on the high leaching soils may have to reduce their N leaching by as much as 75% to meet their regulated limit while similar enterprises in low leaching soils may have to reduce N leaching up to around 45%. Achieving these reductions would require changing land use and/or land management practices.

Overall, arable land uses experience a greater reduction in net revenue under averaging (accounting for both the costs of land moving out of arable land uses and the cost of implementing new management practices); and dairy support fares better under averaging in terms of net revenue. All other enterprises experience similar changes in revenue under both allocation approaches.

Cap and trade Policies

Three allocation approaches were modelled under the assumption that NDAs could be traded between landowners across the entire catchment: grandparenting, nutrient vulnerability, and auctioning the allowances. At the catchment scale, grandparenting and nutrient vulnerability allocation approaches with trading reduced net revenue by 9 to 10%. These approaches freely allocated NDAs to landowners. Auctioning allowances, where landowners had to purchase NDAs, resulted in a 31% reduction in net revenue across the catchment. All scenarios achieved the 45% N reduction target.

For this catchment net revenue for dairy decreases more under grandparenting than the nutrient vulnerability allocation scenario as more land shift out of dairy under grandparenting. In the nutrient vulnerability scenario net revenue for dairy support decreases more than under grandparenting, while the increase in net revenue for sheep and beef is greater than with grandparenting.

Auctioning generates revenue for the regional council. The average price of the auctioned allowances is approximately $22/kg N, generating about $72 million for the council.

Hybrid Policy Approaches

Three ‘hybrid’ policy scenarios were modelled. One scenario combined cap and trade with a resource rental charge. The second scenario allocated NDAs equally to landowners in the same land productivity class and restricted trading of NDAs to these specific classes. The final scenario involved cap and trade in part of the catchment and a farm-specific cap in the rest of the catchment (called a catchment club scenario).

The resource rental policy scenario combined the catchment-wide cap and trade with grandparenting allocation approach with a $2.50/kg N resource rental charge. NZFARM estimated that net farm revenue in the catchment was reduced by 12%, but the resource rental charge generated approximately $8.1 million per annum for the council. For dairy enterprises this is about 12% reduction in net revenue relative to the baseline.

For the equal allocation policy scenario, about 95% of land in the catchment was classified as high productivity land. Results are therefore similar to the catchment-wide cap and trade scenarios. Net revenue was estimated to be reduced by 9% and it achieved the 45% N reduction target.

The catchment club scenario divided the catchment into three zones, two of which correspond to the Mayfield-Hinds and Valetta irrigation scheme areas with zone-restricted trading. In the irrigation scheme zones the allowances are allocated using a grandparenting approach, while averaging is used for the remaining zone which disallows trading. The catchment club results in a decrease in net revenue of about 12% across the catchment. This is slightly larger than the impact of cap and trade with grandparenting scenario, demonstrating that the smaller trading zones may indeed have increased the cost of the policy. However, the farm-specific cap with an average allocation scenario (no trading) reduces net revenue by 14%. So, policy scenarios that offer some greater flexibility through trading appear less costly.

There are some notably different enterprise-level impacts for the hybrid scenarios. Dairy support fares worst under equal allocation and best under a catchment club while dairy fares the best under equal allocation.

6 Discussion and Conclusions

This report considers several different policy scenarios to reduce N leaching from land-based operations in the Hinds catchment. These include requiring landowners to implement mitigation practices, regulating the total N leached within the catchment and allocating this limit to individual landowners (ie, allocating nutrient discharge allowances (NDAs)), and allowing the trading of NDAs between landowners. The scenarios that restrict or cap the N leaching within the catchment consider several allocation approaches (eg, grandparenting, equal allocation, auction, etc.) to distribute the cap between N sources in the catchment, primarily landowners. The scenarios assessed where determined by ECan and the MfE.

To compare between the various policy scenarios beyond changes in net revenue and total N, we consider the following criteria: administration and transaction costs, implementation time, and allocation and distributional impacts. These and some specific implications of the modelled policy scenarios are discussed below.

Administration and Transaction costs

In addition to the costs of nutrient mitigation actions faced by diffuse and point sources of nutrient losses under a nutrient reduction policy, costs associated with developing, implementing, and administering policies also exist. As this report deals primarily with diffuse nutrient losses from land, the discussion outlined below will focus on N leaching from land.

In New Zealand the costs of implementing and administering such policies are expected to be borne primarily by local governments, with landowners paying the cost of implementing nutrient mitigation practices. A policy administered by a regional council or the central government is likely to require public resources and will place a demand on public-sector capabilities. The extent of the resource needed will depend on the final design of the policy.

Some indicative regional council categories of costs for each type of scenario assessed in this report are outlined in Table 38.

Table 38: Indicative regional council cost categories for each type of policy scenario

Cost category	Required adoption of N mitigation practices	Regulating catchment N leaching (cap)	Cap and trade
Initial set up costs	Identify those practices that will be recognised as reducing N leaching or criteria to determine if a practice does reduce N leaching. Develop database to track landowner adoption and compliance. Education and outreach to landowners on the policy.	Establish catchment N leaching cap. Allocate that cap to individual sources and consent or permit the N leaching from these sources. Develop database to track landowner compliance against their allocated N leaching limit. Education and outreach to landowners on the policy.	Establish catchment N leaching cap. Allocate that cap to individual sources and consent or permit the N leaching from these sources. Develop database to track landowner compliance against their allocated N leaching limit and any trades. Develop trading infrastructure such as a marketplace. This is optional*. Education and outreach to landowners on the policy.
On-going operational costs	Maintaining up-to-date information on effectiveness of existing and new mitigation practices. Processing annual compliance reports (or equivalent) from landowners. Compliance and monitoring checks.	Processing annual compliance reports (or equivalent) from landowners. Compliance and monitoring checks.	Processing annual compliance reports (or equivalent) from landowners. Processing any changes in consents related to the trading of allowances. Compliance and monitoring checks.

* If cap and trade programmes are going to be established in a number of catchments in Canterbury it would be worth considering a Canterbury-wide market place.

The likely costs faced by landowners will include researching new and existing mitigation practices, developing and submitting compliance documents (which may include farm-level plans and/or nutrient budgets), any financial costs associated with implementing new N mitigation practices and any loss in revenue (actual or opportunity cost) of change land use or land management. Under a cap and trade programme there will also be the any costs associated with finding a buyer or a seller and costs associated with negotiating and completing a trade (eg, changing consent to reflect more or less NDAs). Depending on whether a farmer is buying or selling NDA, the trade will increase revenue or increase costs to that landowner.

Implementation Time

The effectiveness of a policy can be influenced by the speed at which it is implemented. Land-use change in response to changing market conditions, for instance, is typically a slow process. Evidence suggests that quickly adjusting land use in New Zealand can be costly, and may justify slower transition pathways to minimize cost (Kerr and Olssen, 2012). The implementation timeframe for this analysis assumed that a policy scenario was not fully implemented until 2038, or 25 years from now. This was to allow sufficient time for the regional council to design and implement a policy that ensured maximum compliance with that policy, and provided sufficient time to engage with landowners around how the policy would work. It also provided landowners with the time to transition to new management and/or new land uses at lowest cost. Shorter timeframes may mean that some decisions are not optimal and will increase landowner costs. For instance, having to purchase new irrigation equipment to meet more stringent N leaching limits before the equipment needs replacing. Trading can provide some flexibility for those who wish to delay implementing more expensive practices/technologies or upgrading infrastructure until a time that fits better with the maintenance/replacement schedules for capital equipment or other farm development plans. The trade-off with having longer timeframes is the further or faster degradation of waterways, which could result in a different set of costs to the region (eg, loss of mahinga kai, recreational uses, etc.).

Allocation and Distributional Impacts

Where N leaching is regulated or capped, this cap can be distributed to landowners in the catchment using a number of allocation approaches. Allocation is, by its very nature, challenging as it involves constraining the existing or future use of a resource, in this case land. As a result all landowners will 'lose', either through actual financial costs now or the opportunity costs of not being able to develop (or reduced development) in the future. The decision on the best or optimal allocation approach to use is really a decision based on fairness and equity, and what is fair and equitable is likely to change between catchments. The differing land use and land management configurations between catchments means that the starting point for determining 'who will lose and how much' may vary. Therefore, any discussion on the allocation approach to use should be based on what the community and the council deems to be the most fair and equitable given the current (or reference year) configuration of land use and land characteristics at the catchment context (eg, distribution of high leaching soils).

The policy scenarios modelled with NZFARM investigated several different allocation approaches and this information can be used to assess which sectors were impacted most by the various allocation approaches. Most scenarios in the analysis assumed a 'free allocation' of NDAs with exception of the auctioning approach. The free allocation of allowances effectively works as a lump sum transfer of wealth to the recipient. With an auction, however, all NDAs are purchased from the regulator (ie, regional council), resulting in a transfer of money from the landowner to the council. With trading, a landowner who receives more NDAs than they require to achieve their N leaching limit can sell excess NDAs to those who require additional NDAs. This is sometimes called a 'windfall gain' as that landowner can derive a financial benefit from that allocation approach by selling the excess NDAs or increase production until that higher leaching limit is reached. However, as long as the total number of NDAs allocated reflects the N leaching target, the nutrient reduction goal will be achieved.

Using a trading programme provides some flexibility to those landowners who do not receive a sufficient allocation of NDAs to cover their current N leaching levels and who cannot cost-effectively reduce their N leaching to meet their regulated (or consented) limit. With trading, the resulting outcome in terms of who holds the NDAs will be similar or the same regardless of the initial allocation NDAs across the catchment. In theory, when all landowners are willing to participate in a trading programme the NDAs will move to those landowners who value them the most. All landowners are theoretically willing to pay up to their marginal cost of mitigation for an allowance. Where some landowners choose not to participate in a trading programme then the total cost of the policy may increase, depending on who is not willing to participate. This analysis does account for the potential unwillingness some landowners to participate in trading through the parameterisation of the CET functions in NZFARM. More details are provided in Appendix 4.

Without trading, there is less flexibility for landowners in the catchment to meet their regulated limit at least cost. Depending on the allocation approach, some landowners may receive more

NDAs than they need to cover the N leached in the reference year and other landowners may receive less they need. Where there is no trading there is no ability to move NDAs from landowners that don not need them to others that do. This can also increase the cost of the policy, as each landowner has to meet the limit they were initially allocated. Because some landowners might receive excess allocation, the approach may result in the reduction in N leaching to be greater than the specified target.

Auctioning allowances assumes that all landowners purchase an NDA for every unit of N they leach. In theory, allowances will be purchased by those that value them the most with landowners willing to bid up to their marginal cost of mitigation for an allowance. Therefore, the resulting change in land use and land management will be the same as trading using any of the allocation approaches. The difference is the financial transfer from the landowner to the council for the purchase of allowances. One advantage of generating revenue from the auctioning of NDAs is that there are funds that can be re-distributed back to the community or to landowners. How this funding is re-distributed can take many forms but some examples are reduced rates, financing mitigation practices that are beyond a single landowner (eg, large wetland), investing in infrastructure or providing cost-share (or equivalent) payments to farmers to assist and incentivise implementing more costly mitigation practices.

A resource rental charge differs to the other approaches as it introduces an additional charge to landowners for each kg of N leached. This is on top of any costs a landowner may incur to implement the necessary mitigation practices. The revenue generated by the charge can be used in a similar fashion to the funds generated by auctioning allowances. The challenge with a resource rental charge is how and at what price the charge should be set. There could also be some issues with community and landowner acceptance of a charge that is in addition to the costs incurred to meet the N reduction target. Even a relatively modest rental rate of $2.50 considered in this analysis resulted in the generation of millions of dollars.

Implications of modelled policy scenarios

Improved land management practices scenario

The first policy scenario considered in this report is to require farmers to adopt specific management practice(s). This scenario is perceived by some stakeholders to be relatively easy to administer and monitor.

Management practices that reduce N leaching can be either promoted or required, and the effectiveness of these practices across the catchment can be tracked or not. Tracking the practices implemented and how they differ to current practices will require that the regional council determine what practices currently exist (or did for a reference year) for each landowner and require landowners to report any practice changes to the council. If the council is promoting the adoption of N reducing practices and the change in management practices are not tracked it will not be possible for the council to determine the extent of uptake of N reducing management practices. If the council requires the adoption of N reducing practices then it should be tracking the change in practices for compliance purposes.

The biggest challenge with a practice-based policy is that while it may be effective at getting practice change it may not achieve any environmental improvement. By only tracking practice uptake and not the reduction in N leaching as a result of the practices and overall land management could mean that total N leaching is increasing as landowners continue to intensify their production alongside adopting N reducing practices.

For this report, we modelled the full adoption of the management practices included in the AM1 bundle. This may differ to how a council may implement such a policy. Councils may, instead, develop a list of acceptable practices that landowners can implement, but not require them to implement all listed practices. A more flexible approach would likely result in lower costs to the farmer, but may not achieve as many reductions in N leaching.

The analysis found the full adoption of all practices in the AM1 bundle results in a 39% reduction in total N with a 4% loss in net revenue. Even with full adoption of these AM1 practices by all pastoral and arable landowners in the catchment the 45% N reduction target is not met. Additional policy instruments would be required to achieve the remaining reductions to meet the target.

Farm-specific cap scenarios

Setting farm-specific caps involves a catchment-wide cap to be established and then allocating this cap amongst landowners. Landowners are then required to leach less N than the specified N leaching limit for their land. This limit is articulated in terms of NDAs. Landowners can choose any land use or management practice to stay within their allocated NDAs but they are not allowed to trade their NDAs.

The policy has a slightly lower administrative burden for the council than trading as it does not have to track the trades being made. However, compliance monitoring and reporting will be the greatest administrative burden for this policy and also any policy than involves trading. The absence of trading does reduce the overall flexibility of landowners to meet their regulated limit and in all likelihood will increase the mitigation cost of meeting that limit. If there are landowners who have excess NDA then the efficiency of the policy may suffer, as those excess NDAs are not used. One potential advantage is that there may be a greater reduction in N leaching than is required to meet the target.

Two scenarios are modelled in this report to assess different allocation approaches. One scenario allocates the NDAs uniformly (on a per hectare basis) across the catchment regardless of their land use. The other scenario allocates NDAs using a natural capital approached based on land use capability (LUC) classes across the catchment. Land with lower LUC classes (ie, is more productive) is allocated more NDAs on a per hectare basis than land on higher LUC classes.

The average allocation scenario results in about a 14% loss in net revenue and reduces total N leaching reduction by 51%. This achieves a greater reduction in N leaching than the 45% reduction target for the catchment. Those more intensive landowners, such as dairy and dairy support, on the high leaching soils face higher costs than those on low leaching soils, as they may have to reduce their N leaching by as much as 75% to meet their regulated limit.

In aggregate, the natural capital allocation approach produces similar results to the average allocation approach. However, the arable land uses experience a greater reduction in net revenue under the average allocation approach (accounting for both the costs of land moving out of arable land uses and the cost of implementing new management practices); and dairy support fares better under the average allocation approach in terms of net revenue increases. Other sectors experience similar changes in revenue under both allocation approaches.

If a landowner has been allocated more NDAs than they currently require, they will have more flexibility in how they manage their land and they could intensify their operation. Those landowners on higher leaching soils will be disadvantaged the most under both allocation approaches.

Cap and trade scenarios

A cap and trade programme is a market-based mechanism that involves the establishment of a catchment cap for N leaching, the allocation of this cap to landowners in the form of NDAs and then allows the trading of NDAs between landowners. Cap and trade is premised on landowners having differing costs to reduce nutrients depending on their size, location, scale, management, and overall efficiency. Theoretically, cap and trade is more flexible and cost-effective than the policies discussed earlier that require all landowners to implement certain land management practices or meet individual targets.

A major advantage of trading is the greater flexibility it provides to landowners in how they can meet their regulated limits. Landowners still have the ability to choose the most appropriate N reduction management practices for their context but they can also increase, maintain, or decrease their N leaching rates, as long as they hold sufficient NDAs to cover their N leaching. If they have excess NDAs they can sell them, while if they do not have enough NDAs they can purchase them from another landowner. Landowners who are profit maximisers will mitigate their N leaching as long as their cost of mitigation is less than the market price of a NDA; those with low mitigation costs will mitigate and profit by selling some of their allowances to those with higher mitigation costs. Theoretically, this will equalise the marginal mitigation costs across the catchment, ensuring that mitigation is undertaken by those who can do so at the least cost.

The costs for establishing and running a cap and trade programme are the same as for the farm-specific cap scenario except for any costs associated with registering trades and changing consents for each landowner to reflect any trades that have taken place (see Table 38 above). More sophisticated infrastructure such as marketplaces can also be developed but these are not essential for the operation of a trading programme.

As in the farm-specific cap polices, there is an allocation of the catchment cap to landowners; and this allocation process can be highly contentious. A number of allocation approaches are modelled in this report including grandparenting, equal and nutrient vulnerability allocation, and auctioning the allowances. The auctioning of allowances is assumed to occur once per annum. This determines the initial allocation of allowances to landowners for the year. An average or natural capital allocation approach could also be used in the context of a trading programme, but were not modelled for this report.

At the catchment scale, grandparenting and nutrient vulnerability allocation approaches with trading all reduced net revenue by about 10%. These approaches freely allocated NDAs to landowners. Auctioning allowances, where landowners had to purchase NDAs, resulted in a 31% reduction in net revenue across the catchment. All scenarios achieved the 45% N reduction target.

Net revenue for dairy decreases more for the grandparenting scenario relative to the nutrient vulnerability allocation scenario. In the nutrient vulnerability scenarios, net revenue for dairy support decreases more than grandparenting, while the increase in net revenue for sheep and beef is greater than the grandparenting allocation scenario. These impacts are mainly due to land use changes driven by the NDA allocation limits.

Auctioning reduces net dairy revenue more than the other allocation approaches. Arable and sheep and beef also experience greater reductions in net revenue with the auctioning of allowances than the other approaches. The impact on the net revenue for dairy support is similar to the nutrient vulnerability allocation approaches.

In summary, net revenue for dairy and sheep and beef fares best under the nutrient vulnerability allocations, while dairy support fares best under grandparenting. The other sectors faces similar impacts on net revenue across all allocation approaches modelled.

The average price of the auctioned allowances is around $22/kg N, which is equivalent to the marginal cost of abatement for the other two catchment-wide trading scenarios with free allocation. The auction generates approximately $72.1 million for the council. As noted earlier, these funds can be used in a number of ways that could benefit the landowners.

Hybrid scenarios

Three ‘hybrid’ policy scenarios were modelled. One scenario combined cap and trade with a resource rental charge. The second scenario allocated NDAs equally to landowners in the same land productivity class and restricted trading of NDAs to these specific classes. The final scenario involved cap and trade in part of the catchment and a farm-specific cap in the rest of the catchment (called a catchment club scenario). These scenarios are considered because they have the potential to reduce the administrative burden of policy by either limiting the geographic scope of trading or by creating an additional source of income for the council.

The resource rental charge is similar to a N tax on each kg of N leached. While this charge is collected by the council, the council can re-distribute these funds back to landowners and the community if they so choose. Determining the charge price is challenging and there may be some political resistance by landowners to paying an additional charge on top of the costs to meet their nutrient reduction targets. This modelled policy scenario combined the catchment-wide cap and trade with grandparenting allocation approach with a $2.50/kg N resource rental charge. This reduced net catchment revenue by 12% while generating approximately $8.1 million per annum for the council from the resource rental charge.

The equal allocation scenario is a variant of the averaging and natural capital allocation approaches. The catchment is divided into high and low productive land, with the high productive land being allocated more NDAs on a per hectare basis than low productive land. NDAs can only be traded within the same land productivity class. About 95% of land in the catchment was classified as high productivity land, so results are similar to the catchment-wide cap and trade scenarios. Net revenue was estimated to be reduced by 9% and it achieved the 45% N reduction target.

The catchment club scenario divides the catchment into 3 zones, two of which correspond to the Mayfield-Hinds and Valetta irrigation scheme areas. A cap and trade programme operates in the irrigation scheme zones while N leaching is capped in the other zone but no trading is allowed. In the irrigation scheme zones the allowances are allocated using a grandparenting approach, while an average allocation is used for the remaining zone which disallows trading.

Depending on how the catchment club policy is designed it may be administratively less burdensome for the council. If each club is assigned and consented for an aggregate number of N leaching allowances then the council only has to monitor that the club is in compliance and not the individual landowners in the club. It would be the responsibility of the club to further distribute the allowances to landowners within the club and administer any trades. The landowners in the areas outside the irrigation schemes would still need to demonstrate individual compliance with their individual NDA allocation. This assumes that no overarching entity is created to manage this club, as there is no trading of allowances and therefore no need for such an entity. The reduced size of the nutrient market within each club, however, could increase the price paid for traded NDAs. Clubs may have some advantages over the cap and trade scenarios. The club structure reduces the size of the zone within which trades can occur, thereby potentially reducing the occurrence of 'hotspots'. Hotspots are localised areas of lower water quality resulting from trades which increase N leaching upstream. It may also be easier for buyers and sellers to locate each other within the smaller geographic area of the club and if there is an overarching entity that manages the club.

The catchment club results in a decrease in net revenue of about 12% across the catchment. This is slightly larger than the impact of cap and trade with grandparenting scenario, demonstrating that the smaller trading zones may indeed have increased the cost of the policy. However, the farm-specific cap with an average allocation scenario (no trading) reduces net revenue by 14%. So, policy scenarios that offer some greater flexibility through trading appear less costly.

There are some notably different enterprise-level impacts for the hybrid scenarios. Dairy support fares worst under equal allocation and best under a catchment club while dairy fares the best under equal allocation.

Possible extensions and future analysis

For this analysis, the list of N reducing management practices incorporated was not an exhaustive list. There may be other practices that could cost-effectively reduce N leaching, and its inclusion in the analysis could reduce the overall costs of the policy. NZFARM also assumes that technology remains constant over time and does not account for potential improvements in efficiency over time. It is likely that new mitigation practices and technologies will emerge if diffuse nutrient leaching becomes regulated, as regulation often incentivises innovation.

In terms of the analysis, model runs without Dicyandiamide (DCDs) included as a mitigation practice may provide interesting results on the benefits of DCDs. The farm budgets for the mitigation bundles included in this analysis were developed before Dicyandiamide (DCDs) were taken off the market in January 2013 and therefore this analysis included DCDs. Additional analysis that removed DCDs as a mitigation option would require developing new farm budgets and running them through Overseer v6.

Nine policy scenarios were considered for the catchment. Other feasible scenarios are likely to exist or could emerge in the future. The analysis considered a number of allocation approaches but these approaches were not compared with and without trading. For example, the nutrient vulnerability allocation scenario was only modelled as part of a cap and trade programme. It would be interesting to see how the impacts of these allocation approaches compare with the farm-specific cap scenarios. Similarly, the 'catchment club' policy scenario could be modelled using different allocation mechanisms besides grandparenting and average allocation or alternative approaches to specify the different clubs in the catchment.

The relative impacts of the policy scenarios modelled may change with alternative farm budgets and N leaching rates. For example, a new version of Overseer may estimate different leaching rates for Canterbury soils (relative and absolute) than the current version. This raises the question on whether the nutrient reduction target and policy should be flexible enough account for this type of uncertainty. A sensitivity analysis of these data could be used to develop a range of estimates for a specific policy scenario to provide an indication of how sensitive the costs of meeting a nutrient reduction target is to the variability in these leaching rates.

The analysis only considered one nutrient reduction target for the catchment. As the science and community discussions evolve, these targets may change. Different nutrient reduction targets or input data may change the relative impacts of the policies considered, requiring additional analysis to be undertaken.

Last, NZFARM explicitly assumes that all landowners are profit maximisers. However, it is known that landowners can have several objectives for managing their farm. While NZFARM implicitly accounts for some aspects of farmer behaviour when the baseline is calibrated, it doesn't account for all forms of farmer behaviour. For instance, NZFARM cannot explicitly account for aspects of landowner decision-making such as lifestyle choice and willingness to adopt new management practices. To address this deficiency within NZFARM, Landcare Research is currently developing a spatially explicit agent-based economic model titled Agent-based Rural Land Use New Zealand (ARLUNZ). This links a farmer behaviour model to NZFARM. ARLUNZ is capable of analysing the impact of a variety of policy scenarios on plot level-land use, farm returns, and several environmental indicators such as nutrient leaching and soil erosion. ARLUNZ can also forecast the resulting land use effects caused by changes in social networks and decision-making.

A separate project funded by MfE (Land Owner Behaviour 0165-01-RFP) and the Values, Monitoring and Outcomes (VMO) MBIE programme have recently conducted a rural decision-makers survey to better understand how landowners and managers make decisions and what influences their decisions. The survey for the MfE project covered Canterbury, Southland, and Waikato (Brown et al., 2013), while the VMO programme covered the remaining 13 regions. This information can be used to populate the agent-based modelling component with a more accurate representation of farmer behaviour.

7 Summary

This report provides an assessment of the impacts of four types of policy approaches for reducing nutrients from diffuse sources in the Hinds Catchment. These include: improving land management practices, farm specific caps, cap and trade and hybrid approaches. The analysis shows which policy approaches are able to meet the 45% N leaching reduction target, how each scenario affects catchment net revenue and what land use and land management change may result from each scenario. The analysis highlights some key findings that should form any consideration about the policy scenarios that could be pursued by ECan in the Hinds catchment.

The results from NZFARM are based on the best data and information available for the Hinds catchment at the time this report was written. It should be noted that the costs of meeting the 45% N reduction target could differ if alternative data sources indicate different costs and/or leaching rates. As NZFARM uses representative farms, some landowners in the catchment may actually face higher or lower costs than what are modelled using these representative farms. This analysis also does not account for the broader impacts of changes in land use and land management beyond the farm gate. The flow-on effects from some of the policies investigated in this report could produce a significant change in regional employment and GDP, as well as social and cultural impacts. These aspects were not intended to be a part of this report. Thus, the estimates presented in this report provide just a subset of possible metrics that could be used to determine the best policy to manage nutrients at the catchment-level. Farm- (eg, MRB 2013) and regional- (eg, Olubode-Awosola & Paragahawewa 2013) level analyses of economic impacts of nutrient reduction policies should also be considered along with the NZFARM estimates when determining the most appropriate policy to implement in the catchment.

Improving land management practices, as shown in AM1 scenario, will not achieve the 45% N leaching reduction target suggested for the Hinds catchment. Further, there could be additional intensification of production in the catchment, as total N leaching is not capped. More intensive land uses and management are possible as long as landowners implement improved land management practices. This could therefore increase overall N leaching.

The administrative costs for the scenarios that establish N leaching catchment caps are similar. There are one-time costs associated with establishing the catchment caps, allocating that cap to individual sources, consenting/permitting those sources, developing a database to track landowner compliance against their allocated NDA, and education and outreach to landowners on the new policy. There are also on-going administrative costs for the annual processing of landowner (or perhaps ‘club’) compliance reports (or equivalent) and any compliance and monitoring checks. For scenarios with trading there are the additional one-time expense of developing infrastructure to support trading (such as a marketplace), if that is deemed necessary, and any on-going processing costs for changes to consents related to the trading of allowances.

It should be noted that all scenarios with catchment caps and the allocation of NDAs will require the benchmarking of all land in the catchment. This is to determine whether a landowner is in compliance or not with their allocated NDAs.

Some scenarios generate revenue for the council, principally the use of an auction mechanism to allocate NDAs and the resource rent charge. These could be poorly perceived by landowners because of the extra financial burden above and beyond their costs to meet their allocated N leaching limits. However, the generated revenue could be re-distributed back to landowners and the community to help ease the challenges with meeting an overall 45% N leaching reduction target and individual N leaching limits.

8 Acknowledgements

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Appendix 1 - Key Components of NZFARM

Table 39: Key Components of NZFARM Hinds Catchment

Zones	Soil Type	Land Type	Enterprise	Mitigation Option	Product Output	Environmental Indicators
Hinds_Hills	VL	Pasture	Dairy_1	Base	Milk solids	N leached
May_Hinds	L	Cropland	Dairy_2	GMP	Dairy calves	P lost
Valetta	M	Horticulture	DairySup_1	AM1	Lambs	Methane (CH_4)
Coastal_Plains	XL	Exotic Forest	DairySup_2	AM2	Mutton	Nitrous Oxide (N_2O)
Northern_Plains	H	Native Forest	DairySup	AM3	Wool	Carbon dioxide (CO_2) – on farm energy use
Hinds	PD		Arable_1		Heifers	C Sequestration from forests
LUC_1	PDL		Arable_2		Steers	
LUC_2	Other		Arable_3		Bulls	
LUC_3			Arable_4		Deer	
LUC_4_5			SNB_1		Pigs	
LUC_6			SNB_2		Berryfruit	
LUC_7			SNB_hill		Grapes	
EA_HPL			Pigs		Grains	
EA_LPL			Berryfruit		Seeds	
EA_NPL			Grapes		Vegetables	
Vul_H			Pine		Straw	
Vul_Other			Native Forest		Silage	
Vul_L					Logs for pulp and paper	
Vul_M					Logs for timber	
Vul_VH					Other misc.	
Vul_VL						

The farm budgets for arable, sheep and beef, dairy, dairy support, and viticulture enterprises in NZFARM for the catchment were obtained from MRB (2013). A description of the typical systems of the representative included in the model farms is as follows:

ECAN/AGRESEARCH NUTRIENT PROJECT

FARM SYSTEMS SUMMARY

SHEEP AND BEEF

DL, Reliable RF, Sheep and Beef

- Pasture based system, representing flat land near foothills in medium rainfall areas, with medium soils.
- 30% stock units as breeding ewes breeding replacements and finishing excess progeny.
- Lamb targeting 18kg CW with average sale date of 20th January.
- 60% stock units as cattle finishing, buying as dairy beef calves and targeting 60% prime at 18 months and 40% prime by 22 months.
- 10% stock units as deer finishing targeting 50kg CW.
- Buying straw but making all silage on farm. Wintering some stock on brassica or fodder crops.

Part Irrigated Sheep and Beef

- Pasture based system, partly irrigated on flat land with light to medium soils.
- 30% stock units as lamb finishing, targeting 16.5kgCW for summer lamb and 21kgCW for winter lamb.
- 70% of total lamb finished as summer lamb, 30% of total lamb finished as winter lambs.
- 60% stock units as cattle finishing, buying as dairy beef calves and targeting 70% prime at 18 months and 30% prime by 22 months.
- 10% stock units as deer finishing targeting 52kg CW.
- Most supplements made on farm, extra silage bought in.
- Stock wintered on brassica or fodder crops.
- 5-10% of farm in cereal as part of regrassing programme.

ARABLE

Arable 1 - Process Crops - Full Irrigated

- Process crop system based around juicung carrots, potatoes, peas, beans, sweet corn, with cereal and ryegrass and lamb finishing.
- On deep medium soils.
- Crop Rotation 1: G. Seed > Process Peas > Beans > Potatoes > W. Wheat > GF Oats > Process Corn > W. Wheat
- Crop Rotation 2: G. Seed > Process Peas > Beans > Wheat > Onions > GF Oats > Potatoes > Wheat
- lambs finished on late summer/winter rape and gree feed oats.

Arable 2 - Small Seeds - Full Irrigated

- Vegetable and specialty seed crop system with some cereal and lamb finishing.
- On medium soils.
- Crop rotation 1: G. Seed > Seed Peas > Raddish or Carrot seed > Wheat > White Clover seed > Maize > Wheat
- Crop rotation 2: G. Seed > Raddish or Reed Beet seed > Wheat > Carrot seed > Wheat > White Clover seed > Wheat
- lambs finished on GF rape and grass seed pasture in late summer and winter.

Arable 3 - Livestock and Cereal (Mixed Arable) - Part Irrigated

- 40% of land irrigated, on medium soils, conventional crops (Wheat, Barley, Grass seed) with some finishing livestock.
- 70% of property in crop, 30% property in permenant pasture.
- Crop Rotation: P.Pasture > W. Wheat > W. Wheat > GF Oats > Seed Peas > GF Rape > Sp. Barley > RG Seed > P. Pasture (2 yrs)
- 60% of stock units as cattle, 40% of stock units as winter lamb.
- Cattle targeting 70% prime by 18 months, 30% prime by 22 months.
- Stock winetred on brassica or fodder crops.
- All straws and silages made on farm.

Arable 4 - Livestock and Cereal (Mixed Arable) - Dry Land

- Heavy soils, medium/High rainfall, dry land.
- 70% of property in crop, 30% property in permenant pasture.
- Crop Rotation: P.Pasture > W. Wheat > W. Wheat > GF Oats > Seed Peas > GF Rape > Sp. Barley > RG Seed > P. Pasture (2 yrs)
- 60% of stock units as cattle, 40% of stock units as winter lamb.
- Cattle targeting 70% prime by 18 months, 30% prime by 22 months.
- Stock winetred on brassica or fodder crops.
- All straws and silages made on farm.

DAIRY SUPPORT

Fully Irrigated - Dairy Support

- Medium/Light soils.
- System incorporating the support for rearing heifer replacements and wintering all cows for farms. Growing grain for direct supply.
- 26% farm in winter feed (Kale and Fodder Beet).
- 26% farm in cereal grain or maize silage (13% winter cereal 7% spring cereal and 6% Maize).
- 48% of farm as pasture.
- Crop rotation: Kale > Fodder Beet > Sp. Barley/Maize > W. Wheat > P. Pasture (3 years)
- All supplements required for winter feeding made on farm, excess exported.

Partially Irrigated/High Rainfall - Dairy Support

- Medium/Heavy soils.
- System incorporating a larger percentage of wintering cows and lower percentage of replacement heifers on pasture to compensate for the risks associated with dryland pastrure not growing and therefore livestock not having feed to grow.
- 30% of farm in winter feed (15% kale and 15% fodder beet)
- 30% of farm in cereal grain to be sold direct to user.
- 40% of farm in short rotation pasture.
- Crop Rotation: Kale > Fodder Beet > Sp. Wheat > GFO > Barley > P. Pasture (4 years)
- Majority of supplements made on farm, some silage and straw bought in.

DAIRY

System 5 Dairy - 4.2cows/ha

- High Input dairy farms using more that 1000kgDM/ cow in improted supplements.
- Targeting more than 2000kgMS/ha/year production.
- Effluent discharged on farm.

System 4 Dairy - 3.7 cows/ha

- Medium input Dairy (typical pasture based Dairy farm in canterbury) using less that /cow/year supplement.
- Achieving current average production for area.
- Effluent discharged on farm.

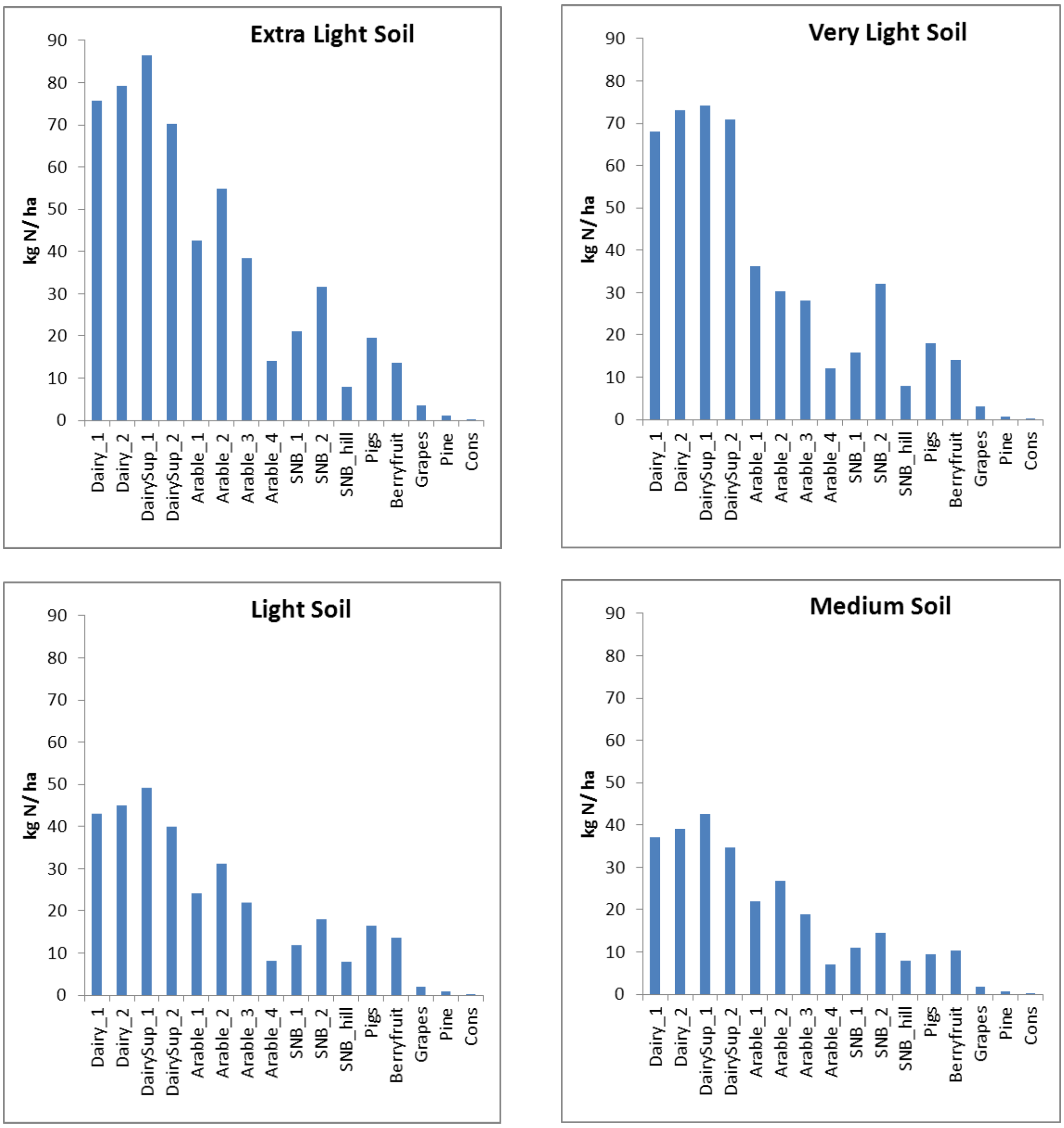
Table 40: Baseline (development scenario) enterprise area ('000 ha) by soil type, Hinds Catchment

Enterprise	Extra Light	Very Light	Light	Medium	Deep	Poorly Drained Light	Poorly Drained	Other	Total
Dairy 1	0.4	12.8	7.4	1.7	0.4	0.1	0.9	0.3	23.9
Dairy 2	0.2	24.1	7.9	1.2	0.9	1.5	4.3	0.1	40.0
DairySup 1	0.4	11.7	6.2	1.1	0.5	0.3	0.9	0.2	21.4
DairySup 2	-	0.2	0.0	-	-	-	-	-	0.2
Arable 1	0.1	1.2	1.3	0.7	0.1	0.1	0.0	0.0	3.6
Arable 2	0.3	5.0	4.0	2.4	0.7	1.3	3.3	0.0	17.0
Arable 3	0.2	0.4	0.2	0.3	1.1	1.2	3.3	0.0	6.7
Arable 4	-	-	-	-	-	0.0	0.1	-	0.2
SNB 1	0.1	0.3	4.9	1.3	0.9	0.2	2.3	0.1	10.1
SNB 2	0.1	0.7	0.2	0.2	0.2	0.5	0.6	0.0	2.4
SNB hill	0.0	0.0	0.6	0.0	0.1	0.0	1.0	4.9	6.6
Pigs	-	-	-	-	0.0	-	0.1	-	0.1
Berryfruit	0.0	0.0	-	-	0.1	-	0.2	-	0.3
Grapes	-	0.0	0.0	-	-	-	0.0	-	0.0
Pine	0.5	0.6	0.7	0.0	0.0	0.0	0.0	0.1	2.0
Native Forest	0.2	0.1	0.0	0.0	0.0		0.0	0.5	0.8
Total	2.5	57.1	33.4	8.8	5.1	5.2	17.0	6.3	135.4

Table 41: N Leaching rates (kgN/ha) by Enterprises for baseline management practices across different Soil Drainage Categories, Hinds Catchment

Enterprise	Extra Light	Very Light	Light	Medium	Deep	Poorly Drained Light	Poorly Drained	Other
Dairy 1	75.7	68.0	43.1	37.2	37.2	26.8	6.9	42.1
Dairy 2	79.2	73.1	45.0	39.0	39.0	28.0	8.0	44.5
DairySup 1	86.5	74.2	49.1	42.6	42.6	30.7	18.8	49.2
DairySup 2	70.2	71.0	39.9	34.7	34.7	25.0	15.1	38.2
Arable 1	42.5	36.2	24.1	21.9	21.9	15.0	9.3	24.4
Arable 2	54.9	30.2	31.2	26.8	26.8	19.1	19.9	29.9
Arable 3	38.5	28.2	21.9	19.0	19.0	13.6	15.2	22.2
Arable 4	14.2	12.0	8.1	7.0	7.0	5.0	4.0	8.2
SNB 1	21.1	15.9	12.0	11.0	11.0	7.6	7.0	12.2
SNB 2	31.6	32.0	18.0	14.5	15.7	11.2	6.8	18.5
SNB hill	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Pigs	19.6	17.9	16.4	9.5	14.1	8.7	6.9	13.3
Berryfruit	13.7	14.0	13.7	10.4	11.3	6.8	5.7	10.8
Grapes	3.5	3.0	2.0	1.7	1.7	1.2	0.7	2.0
Pine	1.1	0.7	0.8	0.7	0.7	0.6	0.5	0.7
Native Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 54: N Leaching (kgN/ha) for Enterprises at the Baseline (no mitigation) across different Soil Drainage Categories, Hinds Catchment



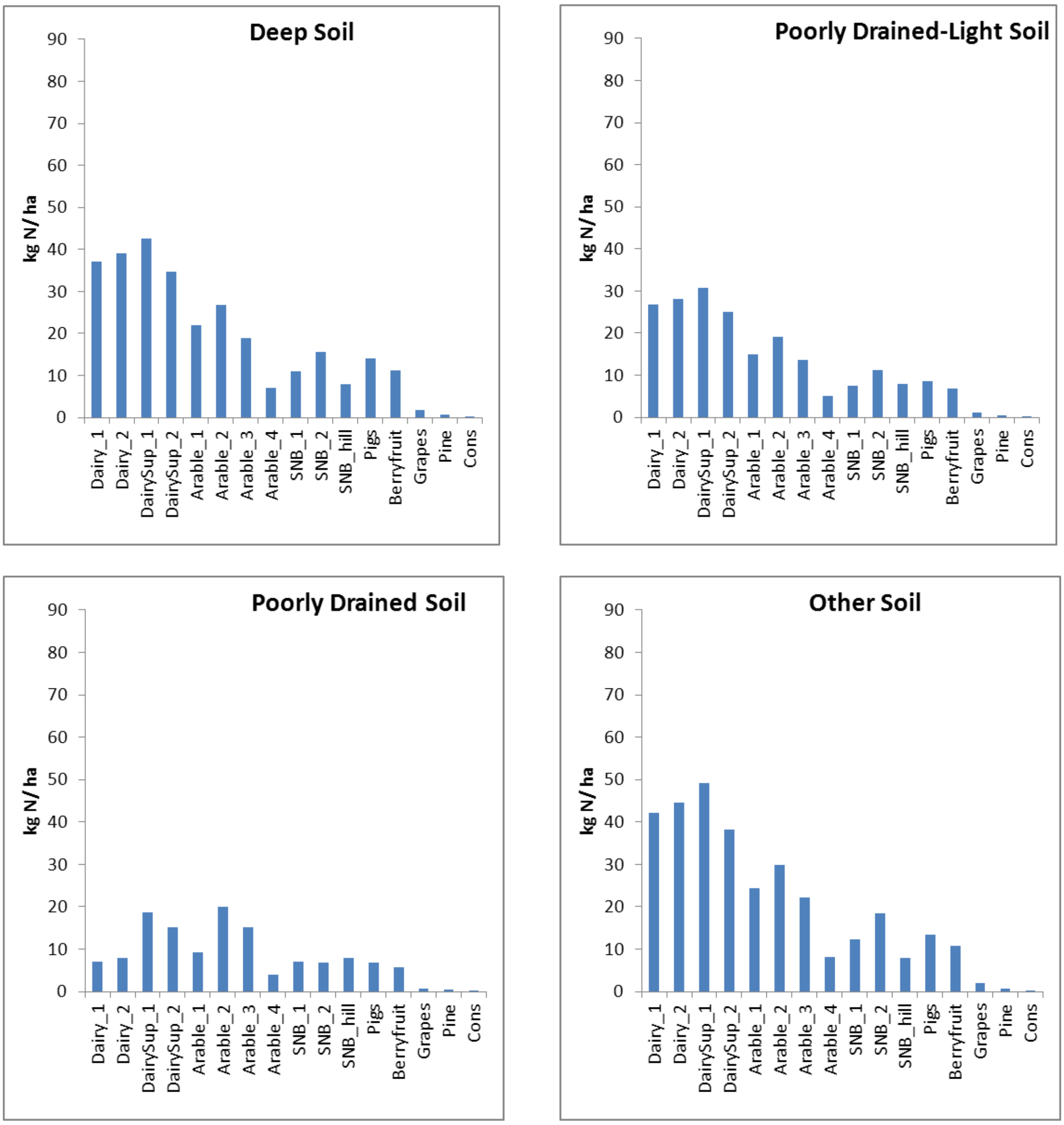

Deep Soil
Poorly Drained-Light Soil
Poorly Drained Soil
Other Soil
kg N/ha
90
80
70
60
50
40
30
20
10
0
Dairy_1
Dairy_2
DairySup_1
DairySup_2
Arable_1
Arable_2
Arable_3
Arable_4
SNB_1
SNB_2
SNB_hill
Pigs
Berryfruit
Grapes
Pine
Cons

Table 42: Key Input Values for NZFARM, Hinds Catchment

Enterprise	Mitigation Practice	Net Revenue ($/ha)	Cash Farm Surplus ($/ha)	N Leach (kg/ha)	P loss (kg/ha)	GHG Emissions (kg/ha)
Dairy 1 (VL)	Base	$ 4,289	$ 884	68.0	0.70	12,115
	GMP	$ 4,226	$ 838	62.8	0.80	12,051
	AM1	$ 4,438	$ 991	27.2	0.70	10,739
	AM2	$ 4,339	$ 920	25.1	0.70	10,734
	AM3	$ 3,216	$ 111	10.5	0.70	9,681
Dairy 2 (VL)	Base	$ 3,686	$ 835	73.1	0.80	10,195
	GMP	$ 3,669	$ 823	73.1	0.80	10,206
	AM1	$ 3,523	$ 719	58.5	1.00	9,292
	AM2	$ 3,342	$ 589	33.6	0.70	10,105
	AM3	$ 2,607	$ 59	16.1	0.70	9,069
Dairy Support 1 (VL)	Base	$ 1,140	$ 319	74.2	0.50	664
	GMP	$ 1,164	$ 336	72.1	0.50	639
	AM1	$ 933	$ 170	34.5	0.50	496
	AM2	$ 819	$ 88	23.0	0.10	521
	AM3	$ 793	$ 70	11.5	0.10	508
Dairy Support 2 (L)	Base	$ 1,167	$ 492	40.0	0.40	453
	GMP	$ 1,180	$ 500	38.0	0.40	428
	AM1	$ 952	$ 336	22.0	0.40	312
	AM2	$ 853	$ 265	16.0	0.10	315
	AM3	$ 448	-$ 37	9.0	0.10	274
Arable 1 (M)	Base	$ 1,983	$ 419	22.0	0.70	1,005
	GMP	$ 1,983	$ 419	22.0	0.70	1,005
	AM1	$ 1,826	$ 275	9.9	0.30	907
	AM2	$ 1,698	$ 187	7.7	0.10	1,053
	AM3	$ 1,706	$ 195	7.7	0.10	989
Arable 2 (L)	Base	$ 1,914	$ 530	31.2	0.30	938
	GMP	$ 1,914	$ 530	31.2	0.30	938
	AM1	$ 1,862	$ 491	19.4	0.10	796
	AM2	$ 1,785	$ 428	15.1	0.00	870
	AM3	$ 1,761	$ 414	14.0	0.00	827
Arable 3 (M)	Base	$ 1,078	$ 263	19.0	0.60	759
	GMP	$ 1,078	$ 263	19.0	0.60	759
	AM1	$ 918	$ 146	10.6	0.60	669
	AM2	$ 694	-$ 21	8.4	0.20	917
	AM3	$ 397	-$ 318	6.3	0.20	794
Arable 4 (PD)	Base	$ 561	$ 170	4.0	0.10	424
	GMP	$ 561	$ 170	4.0	0.10	424
	AM1	$ 470	$ 102	4.0	0.00	355
	AM2	$ 321	-$ 4	5.0	0.00	742
	AM3	$ 371	$ 32	5.0	0.00	632
Sheep and Beef 1 (M)	Base	$ 495	$ 171	11.0	1.20	4,159
	GMP	$ 495	$ 171	11.0	1.20	4,159
	AM1	$ 366	$ 78	7.7	0.20	4,101
	AM2	$ 366	$ 78	7.7	0.20	4,101
	AM3	$ 304	$ 34	7.7	0.20	3,685
Sheep and Beef 2 (L)	Base	$ 326	$ 7	18.0	1.10	4,171
	GMP	$ 343	$ 19	18.0	1.10	4,171
	AM1	$ 306	-$ 11	12.0	0.30	4,097
	AM2	$ 400	$ 60	9.0	0.10	4,510
	AM3	$ 317	$ 1	8.0	0.10	4,177
Sheep and Beef Hill (M)	Base	$ 495	$ 171	8.0	1.20	4,159
	GMP	$ 495	$ 171	8.0	1.20	4,159
	AM1	$ 366	$ 78	5.6	0.20	4,101
	AM2	$ 366	$ 78	5.6	0.20	4,101
	AM3	$ 304	$ 34	5.6	0.20	3,685
Pigs (H)	Base	$ 1,285	$ 385	14.1	0.0	2,588
Berryfruit (PD)	Base	$ 10,791	$ 5,395	5.7	0.1	2,472
Grapes (L)	Base	$ 5,566	$ 2,622	2.0	0.0	2,225
Pine (L)	Base	$ 650	$ 180	0.8	0.0	-15,000
Native Forest (XL)	Base	-	$ -	0.0	0.0	-2,000

Table 43: Percent of Baseline (no mitigation) Values, Hinds Catchment

Enterprise	Mitigation Practice	Net Revenue ($/ha)	Cash Farm Surplus ($/ha)	N Leach (kg/ha)	P loss (kg/ha)	GHG Emissions (kg/ha)
Dairy 1 (VL)	Base	100%	100%	100%	100%	100%
	GMP	99%	95%	92%	114%	99%
	AM1	103%	112%	40%	100%	89%
	AM2	101%	104%	37%	100%	89%
	AM3	75%	13%	15%	100%	80%
Dairy 2 (VL)	Base	100%	100%	100%	100%	100%
	GMP	100%	99%	100%	100%	100%
	AM1	96%	86%	80%	125%	91%
	AM2	91%	71%	46%	88%	99%
	AM3	71%	7%	22%	88%	89%
Dairy Support 1 (VL)	Base	100%	100%	100%	100%	100%
	GMP	102%	105%	97%	100%	96%
	AM1	82%	53%	46%	100%	75%
	AM2	72%	28%	31%	20%	79%
	AM3	70%	22%	15%	20%	77%
Dairy Support 2 (L)	Base	100%	100%	100%	100%	100%
	GMP	101%	102%	95%	100%	94%
	AM1	82%	68%	55%	100%	69%
	AM2	73%	54%	40%	25%	70%
	AM3	38%	-8%	23%	25%	61%
Arable 1 (M)	Base	100%	100%	100%	100%	100%
	GMP	100%	100%	100%	100%	100%
	AM1	92%	66%	45%	43%	90%
	AM2	86%	45%	35%	14%	105%
	AM3	86%	47%	35%	14%	98%
Arable 2 (L)	Base	100%	100%	100%	100%	100%
	GMP	100%	100%	100%	100%	100%
	AM1	97%	93%	62%	33%	85%
	AM2	93%	81%	48%	0%	93%
	AM3	92%	78%	45%	0%	88%
Arable 3 (M)	Base	100%	100%	100%	100%	100%
	GMP	100%	100%	100%	100%	100%
	AM1	85%	56%	56%	100%	88%
	AM2	64%	-8%	44%	33%	121%
	AM3	37%	-121%	33%	33%	105%
Arable 4 (PD)	Base	100%	100%	100%	100%	100%
	GMP	100%	100%	100%	100%	100%
	AM1	84%	60%	100%	0%	84%
	AM2	57%	-2%	125%	0%	175%
	AM3	66%	19%	125%	0%	149%
Sheep and Beef 1 (M)	Base	100%	100%	100%	100%	100%
	GMP	100%	100%	100%	100%	100%
	AM1	74%	46%	70%	17%	99%
	AM2	74%	46%	70%	17%	99%
	AM3	61%	20%	70%	17%	89%
Sheep and Beef 2 (L)	Base	100%	100%	100%	100%	100%
	GMP	105%	271%	100%	100%	100%
	AM1	94%	-157%	67%	27%	98%
	AM2	123%	857%	50%	9%	108%
	AM3	97%	14%	44%	9%	100%
Sheep and Beef Hill (M)	Base	100%	100%	100%	100%	100%
	GMP	100%	100%	100%	100%	100%
	AM1	74%	46%	70%	17%	99%
	AM2	74%	46%	70%	17%	99%
	AM3	61%	20%	70%	17%	89%
Pigs (H)	Base	100%	100%	100%	100%	100%
Berryfruit (PD)	Base	100%	100%	100%	100%	100%
Grapes (L)	Base	100%	100%	100%	100%	100%
Pine (L)	Base	100%	100%	100%	100%	100%
Native Forest (XL)	Base	100%	100%	100%	100%	100%

Appendix 2 – Dynamic Results for NZFARM Policy Scenarios

Estimates for all policy scenarios presented in main report were for the case where the policy scenario was fully implementation in 2038. The following tables show the dynamic transition from a baseline, no-policy case in 2013 to full implementation in 2038. We assumed that current land use would transition to the land use projected under development scenario land use where 30,000 ha of new irrigation are available by 2018 Almost all policy scenarios assume a straight line, incremental implementation of the policy or reduction in N from 2018 through 2038. The one exception is the full adoption of the GMP bundle by all applicable landowners, which is assumed to be fully implemented by 2018. The trajectory of N leaching for the baseline and policy scenarios is shown in Figure 55.

Figure 55: N Leaching (tN/yr) over time for baseline and policy scenarios

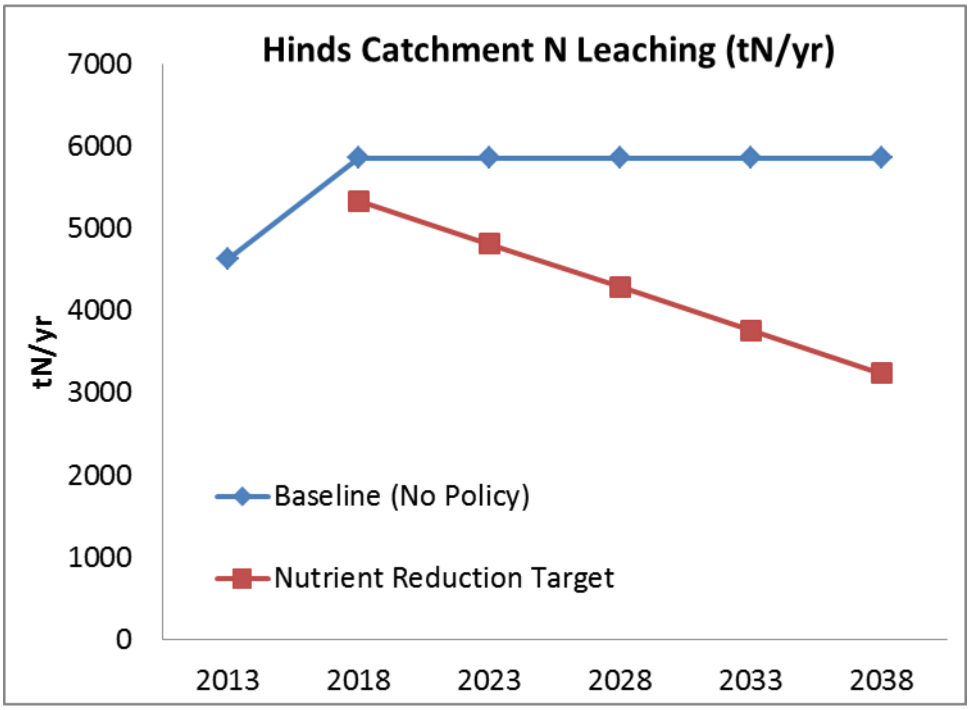


Table 44: Baseline (No Policy)

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	246.7	59.3	$0.0	4,628	105	674,739	$0.0
2018	338.0	79.4	$0.0	5,860	92	791,631	$0.0
2023	338.0	79.4	$0.0	5,860	92	791,631	$0.0
2028	338.0	79.4	$0.0	5,860	92	791,631	$0.0
2033	338.0	79.4	$0.0	5,860	92	791,631	$0.0
2038	338.0	79.4	$0.0	5,860	92	791,631	$0.0

Table 45: Advanced Mitigation 1 (AM1)

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	246.7	59.3	$0.0	4,628	105	674,739	$0.0
2018	335.4	77.7	$0.0	5,402	90	775,304	$5.7
2023	332.8	75.9	$0.0	4,944	87	758,977	$5.7
2028	330.1	74.2	$0.0	4,486	85	742,649	$5.7
2033	327.5	72.4	$0.0	4,028	83	726,322	$5.7
2038	324.9	70.7	$0.0	3,570	81	709,995	$5.7
Percent Change from Baseline							
2013	0%	0%	n/a	0%	0%	0%	n/a
2018	-1%	-2%	n/a	-8%	-2%	-2%	n/a
2023	-2%	-4%	n/a	-16%	-5%	-4%	n/a
2028	-2%	-7%	n/a	-23%	-7%	-6%	n/a
2033	-3%	-9%	n/a	-31%	-10%	-8%	n/a
2038	-4%	-11%	n/a	-39%	-12%	-10%	n/a

Table 46: Average Allocation

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	$246.7	$59.3	$0.0	4,628	105	674,739	$0.0
2018	$318.1	$72.8	$0.0	4,231	86	726,278	$12.2
2023	$313.4	$71.1	$0.0	3,943	85	711,359	$12.9
2028	$307.7	$69.0	$0.0	3,609	83	695,987	$13.5
2033	$300.9	$66.6	$0.0	3,271	82	677,094	$14.3
2038	$291.8	$63.3	$0.0	2,881	79	652,004	$15.4
Percent Change from Baseline							
2013	0%	0%	n/a	0%	0%	0%	n/a
2018	-6%	-8%	n/a	-28%	-6%	-8%	n/a
2023	-7%	-10%	n/a	-33%	-8%	-10%	n/a
2028	-9%	-13%	n/a	-38%	-9%	-12%	n/a
2033	-11%	-16%	n/a	-44%	-11%	-14%	n/a
2038	-14%	-20%	n/a	-51%	-14%	-18%	n/a

Table 47: Natural Capital Allocation

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	$246.7	$59.3	$0.0	4,628	105	674,739	$0.0
2018	$324.6	$76.2	$0.0	4,619	90	765,082	$10.8
2023	$319.3	$74.6	$0.0	4,260	88	750,241	$11.7
2028	$312.5	$71.9	$0.0	3,843	87	732,883	$12.6
2033	$303.8	$68.5	$0.0	3,413	86	709,897	$14.0
2038	$291.0	$61.9	$0.0	2,912	78	669,373	$15.9
Percent Change from Baseline							
2013	0%	0%	n/a	0%	0%	0%	n/a
2018	-4%	-4%	n/a	-21%	-2%	-3%	n/a
2023	-6%	-6%	n/a	-27%	-4%	-5%	n/a
2028	-8%	-9%	n/a	-34%	-5%	-7%	n/a
2033	-10%	-14%	n/a	-42%	-7%	-10%	n/a
2038	-14%	-22%	n/a	-50%	-16%	-15%	n/a

Table 48: Grandparent Allocation + Trading

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	$246.7	$59.3	$0.0	4,628	105	674,739	$0.0
2018	$333.8	$78.0	$0.0	5,336	91	786,025	$8.0
2023	$329.6	$76.1	$0.0	4,812	89	779,767	$8.0
2028	$323.8	$73.8	$0.0	4,288	86	765,054	$9.0
2033	$315.8	$71.1	$0.0	3,764	83	737,460	$10.6
2038	$306.0	$67.5	$0.0	3,212	79	700,319	$12.1
2013	0%	0%	n/a	0%	0%	0%	n/a
2018	-1%	-2%	n/a	-9%	-1%	-1%	n/a
2023	-2%	-4%	n/a	-18%	-3%	-1%	n/a
2028	-4%	-7%	n/a	-27%	-6%	-3%	n/a
2033	-7%	-10%	n/a	-36%	-10%	-7%	n/a
2038	-9%	-15%	n/a	-45%	-14%	-12%	n/a

Table 49: Nutrient Vulnerability Allocation + Trading

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	$246.7	$59.3	$0.0	4,628	105	674,739	$0.0
2018	$331.1	$77.2	$0.0	5,135	91	808,495	$9.5
2023	$327.3	$75.5	$0.0	4,657	90	810,196	$8.9
2028	$322.0	$73.6	$0.0	4,174	88	801,715	$9.5
2033	$314.7	$71.4	$0.0	3,691	86	778,529	$10.7
2038	$306.0	$68.5	$21.0	3,240	84	752,187	$12.2
Percent Change from Baseline							
2013	0%	0%	n/a	0%	0%	0%	n/a
2018	-2%	-3%	n/a	-12%	-1%	2%	n/a
2023	-3%	-5%	n/a	-21%	-2%	2%	n/a
2028	-5%	-7%	n/a	-29%	-4%	1%	n/a
2033	-7%	-10%	n/a	-37%	-7%	-2%	n/a
2038	-9%	-14%	n/a	-45%	-9%	-5%	n/a

Table 50: Auction Allocation + Trading

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)	Auction NDA Value ($/kgN)
Estimated Values								
2013	$246.7	$59.3	$0.0	4,628	105	674,739	$0.0	$0.0
2018	$300.6	$44.8	$33.2	5,336	91	786,025	$71.4	$6.2
2023	$283.9	$30.4	$45.7	4,812	89	779,767	$51.6	$9.5
2028	$268.3	$18.3	$55.5	4,288	86	765,054	$44.3	$12.9
2033	$249.9	$5.2	$66.0	3,764	83	737,460	$42.0	$17.5
2038	$233.3	-$4.5	$72.1	3,240	80	706,209	$40.0	$22.2
Percent Change from Baseline								
2013	0%	0%	n/a	0%	0%	0%	n/a	n/a
2018	-11%	-44%	n/a	-9%	-1%	-1%	n/a	n/a
2023	-16%	-62%	n/a	-18%	-3%	-1%	n/a	n/a
2028	-21%	-77%	n/a	-27%	-6%	-3%	n/a	n/a
2033	-26%	-93%	n/a	-36%	-10%	-7%	n/a	n/a
2038	-31%	-106%	n/a	-45%	-13%	-11%	n/a	n/a

Table 51: Grandparent + Trading with Resource Rent*

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	$246.7	$59.3	$0.0	4,628	105	674,739	$0.0
2018	$331.1	$78.0	$2.7	5,336	91	786,025	$13.1
2023	$324.8	$76.1	$4.8	4,812	89	779,767	$12.6
2028	$317.4	$73.8	$6.4	4,288	86	765,054	$13.1
2033	$308.3	$71.1	$7.5	3,764	83	737,460	$14.2
2038	$297.2	$59.5	$8.1	3,240	80	706,240	$15.6
Percent Change from Baseline							
2013	0%	0%	n/a	0%	0%	0%	n/a
2018	-2%	-2%	n/a	-9%	-1%	-1%	n/a
2023	-4%	-4%	n/a	-18%	-3%	-1%	n/a
2028	-6%	-7%	n/a	-27%	-6%	-3%	n/a
2033	-9%	-10%	n/a	-36%	-10%	-7%	n/a
2038	-12%	-25%	n/a	-45%	-13%	-11%	n/a

* Resource rental rate assumed to increase incrementally from $0.50 to $2.50/kgN from 2018-2038

Table 52: Equal Allocation + Trading

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	$246.7	$59.3	$0.0	4,628	105	674,739	$0.0
2018	$334.6	$78.2	$0.0	5,197	92	799,093	$5.2
2023	$330.8	$76.6	$0.0	4,699	90	797,611	$6.2
2028	$325.5	$74.8	$0.0	4,207	88	783,765	$7.6
2033	$317.9	$72.5	$0.0	3,709	86	753,853	$9.3
2038	$308.8	$69.6	$0.0	3,240	84	721,309	$11.1
Percent Change from Baseline							
2013	0%	0%	n/a	0%	0%	0%	n/a
2018	-1%	-2%	n/a	-11%	0%	1%	n/a
2023	-2%	-4%	n/a	-20%	-2%	1%	n/a
2028	-4%	-6%	n/a	-28%	-4%	-1%	n/a
2033	-6%	-9%	n/a	-37%	-6%	-5%	n/a
2038	-9%	-12%	n/a	-45%	-9%	-9%	n/a

Table 53: Catchment Club Allocation + Trading

Year	Net Farm Revenue (million $)	Cash Farm Surplus (million $)	Regional Council Revenue (million $)	N Leaching (tonnes)	P Loss (tonnes)	GHG Emissions (tonnes)	Average Abatement Cost ($/kgN)
Estimated Values							
2013	$246.7	$59.3	$0.0	4,628	105	674,739	$0.0
2018	$327.1	$76.2	$0.0	4,828	91	764,989	$10.6
2023	$322.8	$74.6	$0.0	4,449	89	751,108	$10.8
2028	$316.7	$72.2	$0.0	4,017	85	727,787	$11.5
2033	$309.3	$69.3	$0.0	3,600	82	705,519	$12.7
2038	$299.0	$65.2	$0.0	3,135	76	678,034	$14.3
Percent Change from Baseline							
2013	0%	0%	n/a	0%	0%	0%	n/a
2018	-3%	-4%	n/a	-18%	-1%	-3%	n/a
2023	-5%	-6%	n/a	-24%	-3%	-5%	n/a
2028	-6%	-9%	n/a	-31%	-7%	-8%	n/a
2033	-8%	-13%	n/a	-39%	-11%	-11%	n/a
2038	-12%	-18%	n/a	-46%	-18%	-14%	n/a

Appendix 3 – Spatial Representation of Policy Scenario Impacts Relative to Baseline

We have created spatially explicit maps for each of the 10 policy scenarios for three key outputs: net revenue, cash farm surplus, and N Leaching. Estimates of these key outputs depict percentage changes for each policy scenario compared to the baseline (development scenario). This was done by disaggregating representative farm estimates by NZFARM zone, soil type, and enterprise and overlaying the estimates from NZFARM over the baseline land use map; for example, all dairy farms on a particular soil type in the Mayfield-Hinds zone are assumed to have the same percentage change relative to the baseline.

NZFARM estimates aggregate area of land use change but does not have the capacity to predict land use change at a finer spatial resolution to be shown in a land use map. These maps do not account for the impacts of any land use change that may result from in the policy scenarios. Thus, if a parcel was designated as Dairy System 1 in the baseline land use map, it is assumed that particular parcel will remain in Dairy system 1. The key output estimates will reflect the impact of trading, change in management system or cost of the policy scenario above the baseline (eg, resource rental payment), if applicable. Note that the relative impacts may be different than what is presented here if land use change has occurred in a particular parcel under the policy scenarios.

Figures 58, 61 and 64 show the relative change in N leaching, net revenue and cash farm surplus, respectively, compared to the baseline. Figures 56, 59, and 62 show the baseline N leaching, net revenue and cash farm surplus, respectively and are included for reference. Figures 57, 60 and 63 show the total N leaching, net revenue and cash farm surplus, respectively for the baseline and each of the policy scenarios.

Figure 56: Baseline N leaching (kg/ha), Hinds Catchment

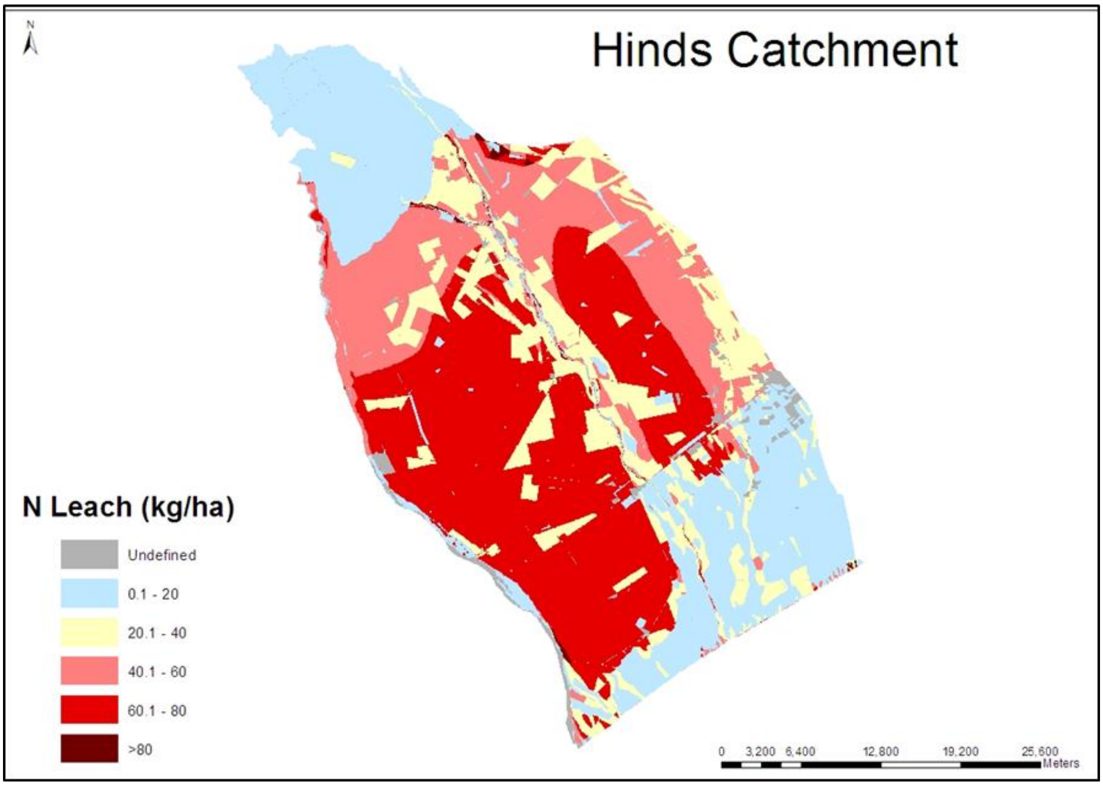


Figure 57: Total N leaching (tN/yr), Hinds Catchment Policy Scenarios

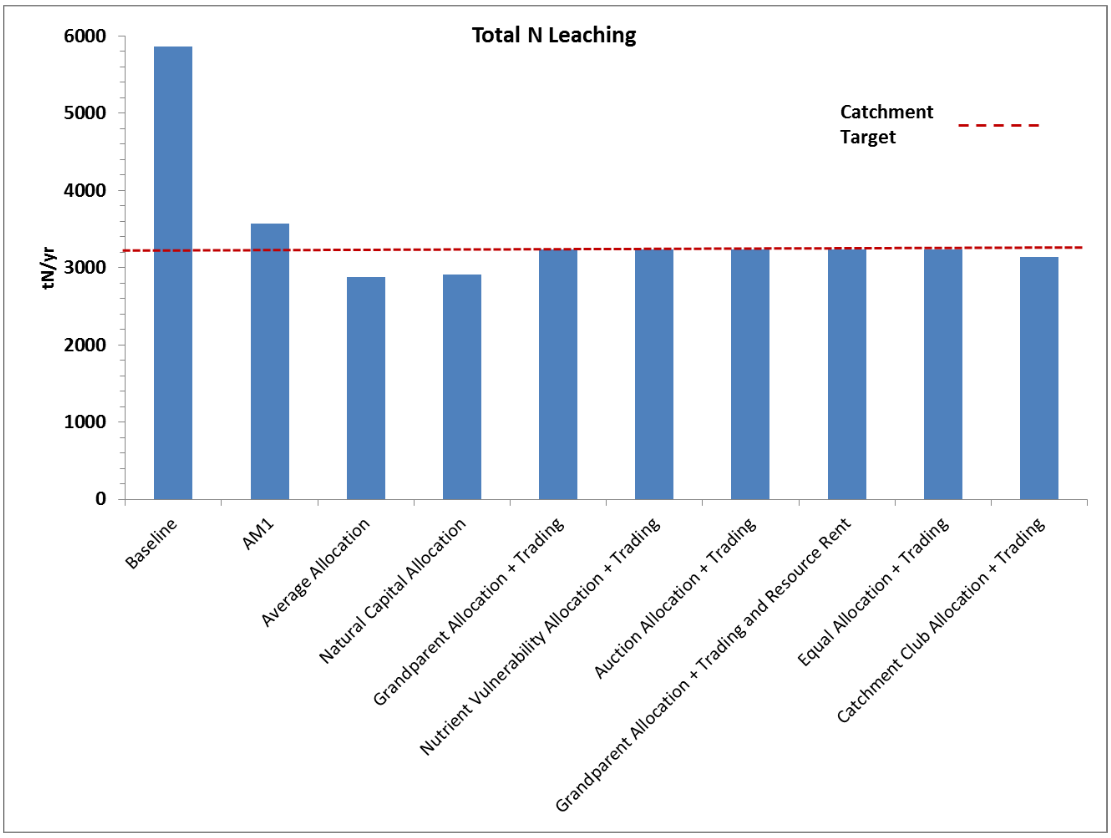
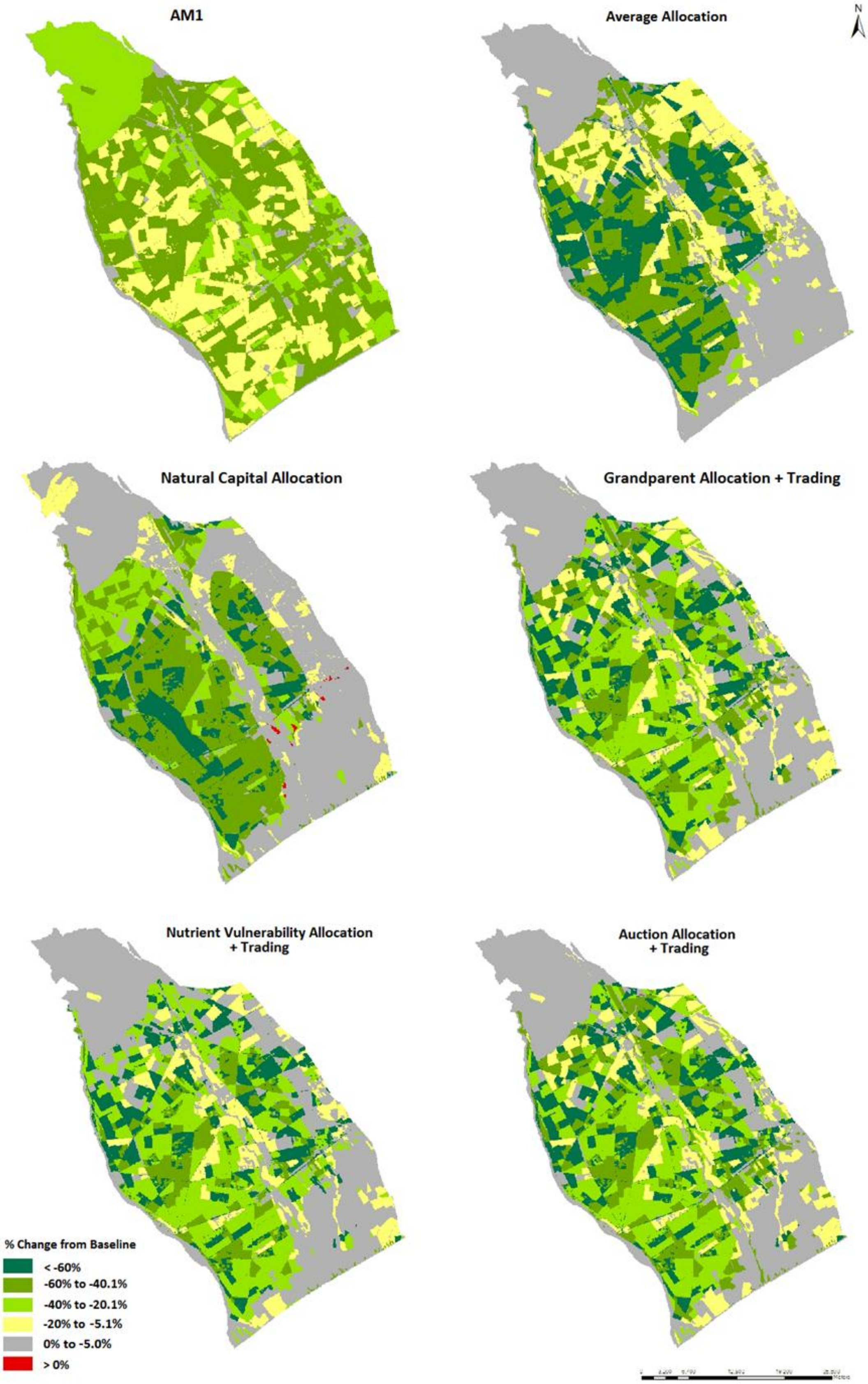


Figure 58: Percentage Change in N Leaching (kg/ha) from the Baseline



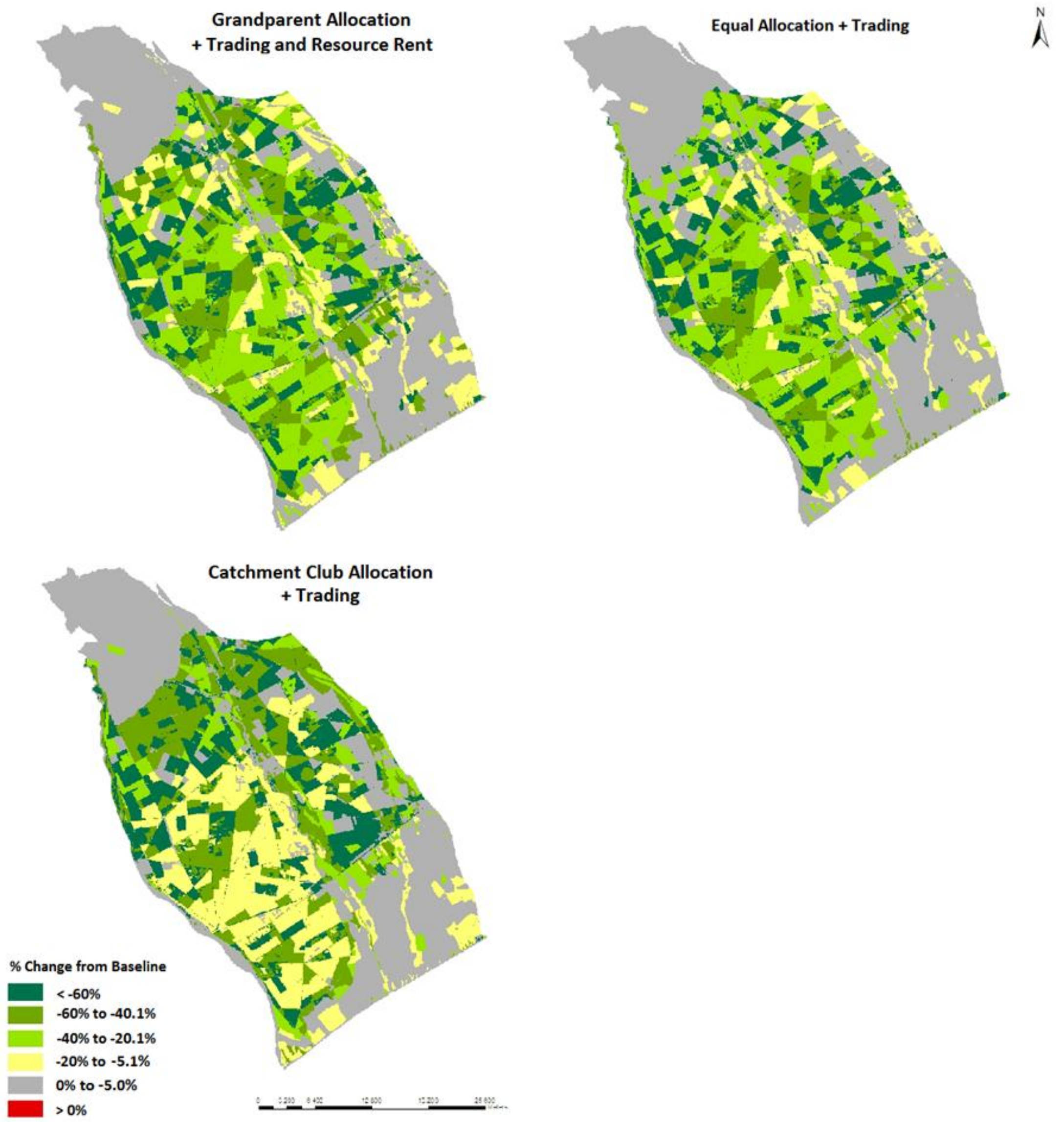

Grandparent Allocation
+ Trading and Resource Rent
Equal Allocation + Trading
N
Catchment Club Allocation
+ Trading
% Change from Baseline
< -60%
-60% to -40.1%
-40% to -20.1%
-20% to -5.1%
0% to -5.0%
> 0%

Figure 59: Baseline Net Farm Revenue ($/ha), Hinds Catchment

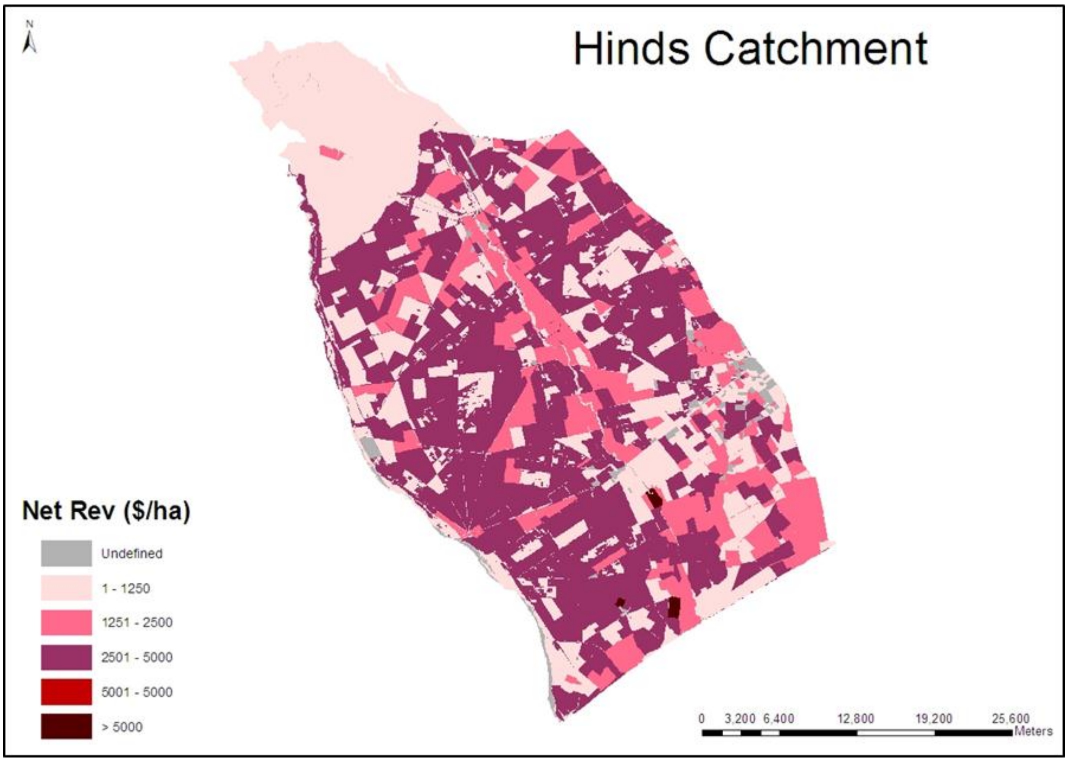


Figure 60: Total Net Farm Revenue ($/ha), Hinds Catchment Policy Scenarios

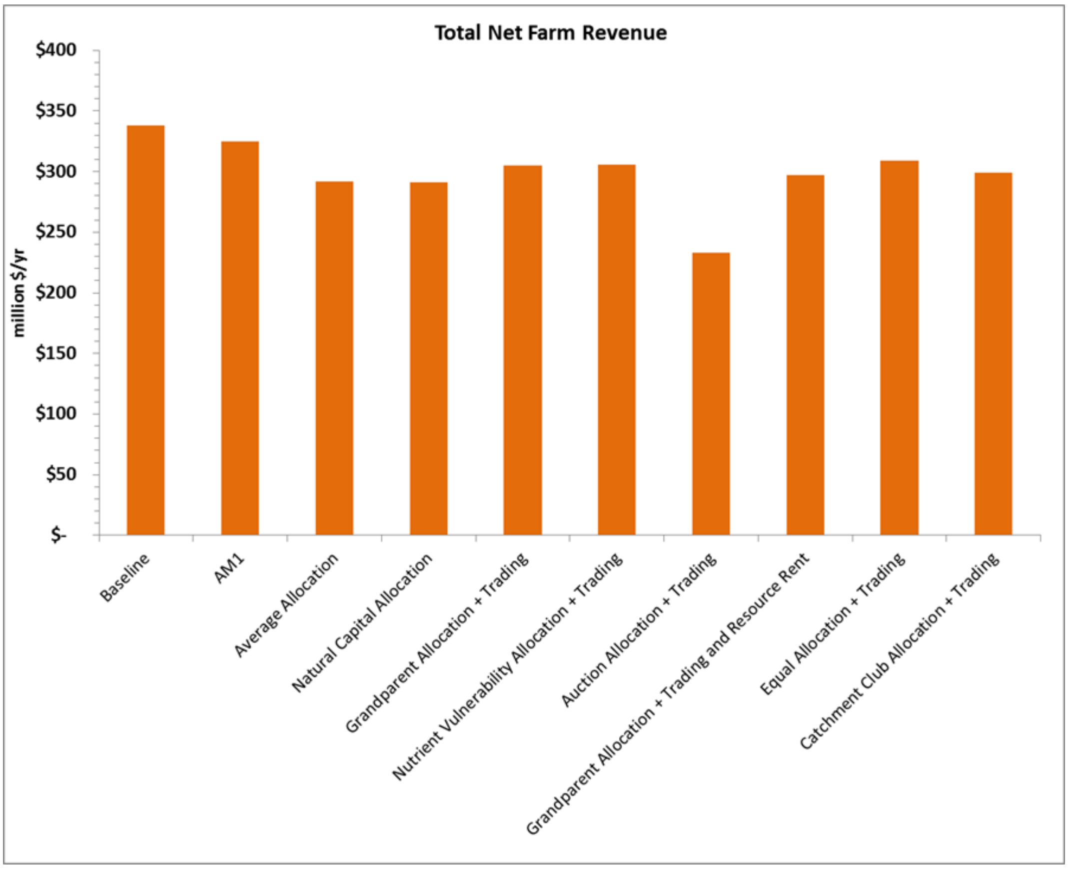
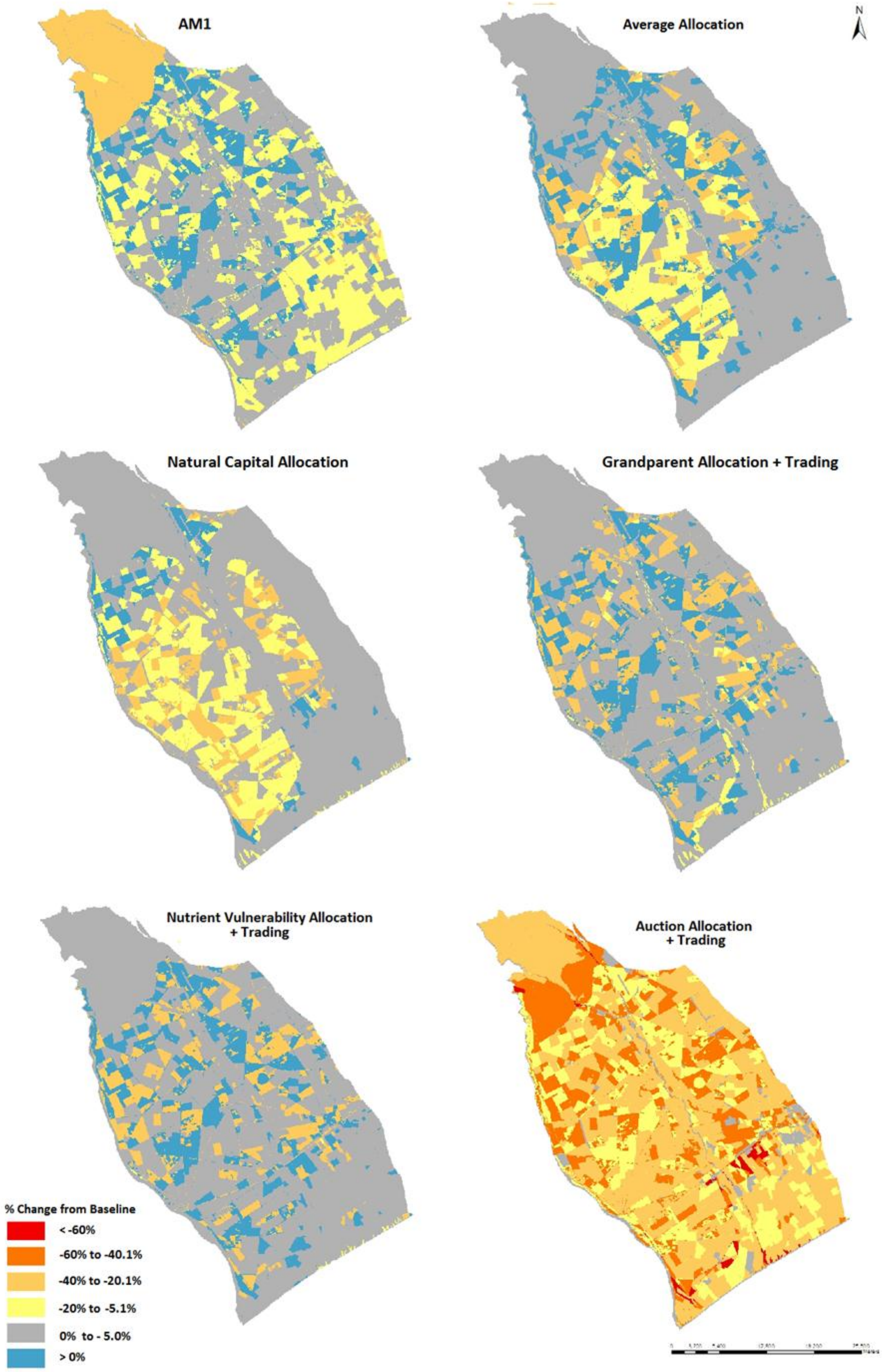


Figure 61: Percentage Change in Net Farm Revenue ($/ha) from the Baseline



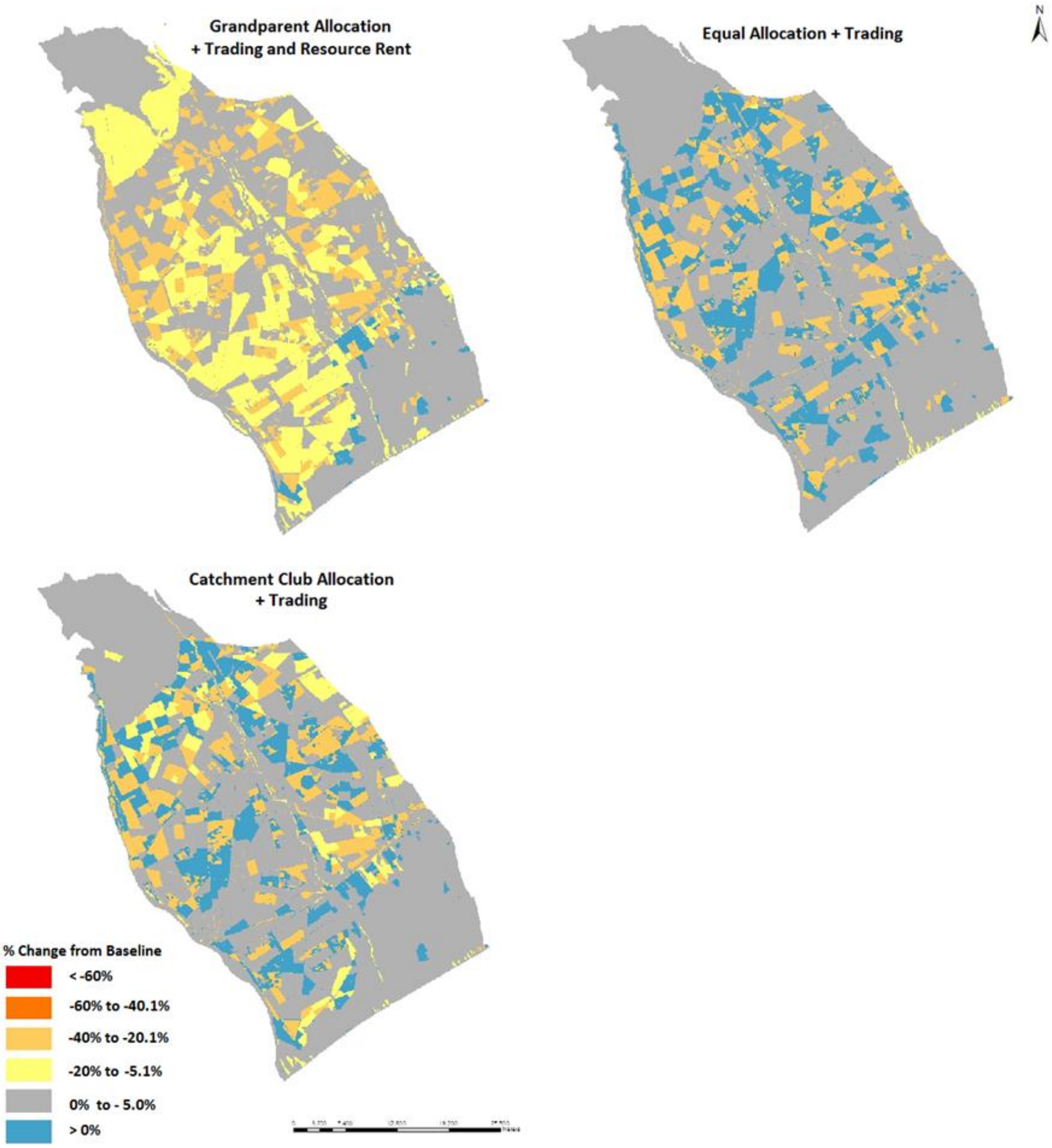

Grandparent Allocation
+ Trading and Resource Rent
Equal Allocation + Trading
N
Catchment Club Allocation
+ Trading
% Change from Baseline
< -60%
-60% to -40.1%
-40% to -20.1%
-20% to -5.1%
0% to - 5.0%
> 0%

Figure 62: Baseline Cash Farm Surplus ($/ha), Hinds Catchment

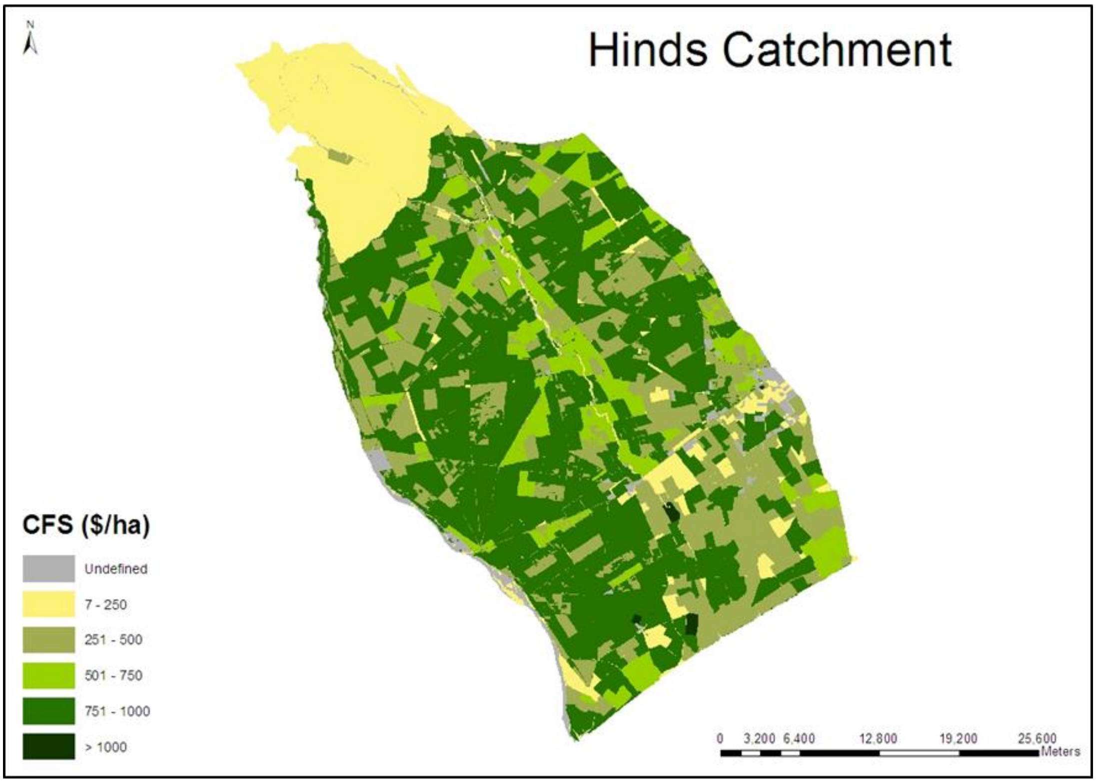


Figure 63: Total Cash Farm Surplus ($/ha), Hinds Catchment Policy Scenarios

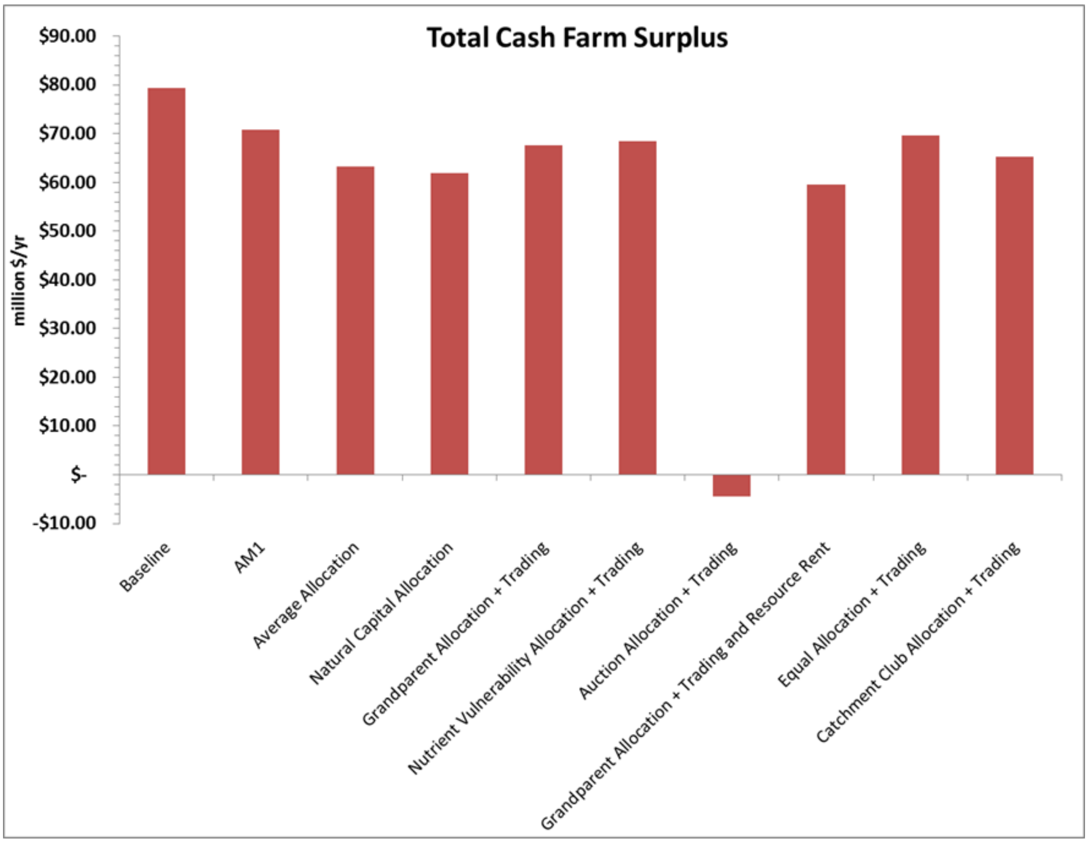
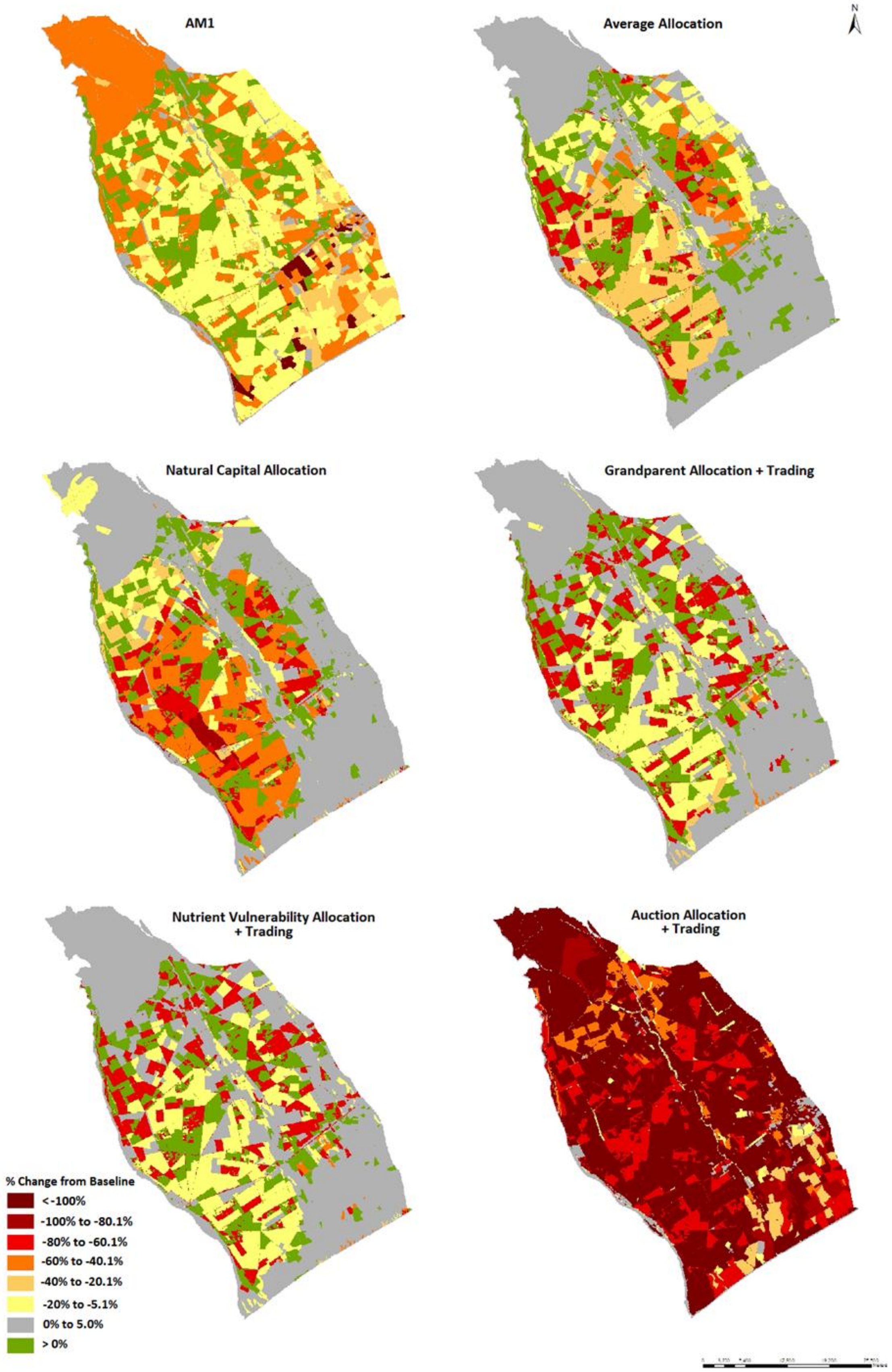
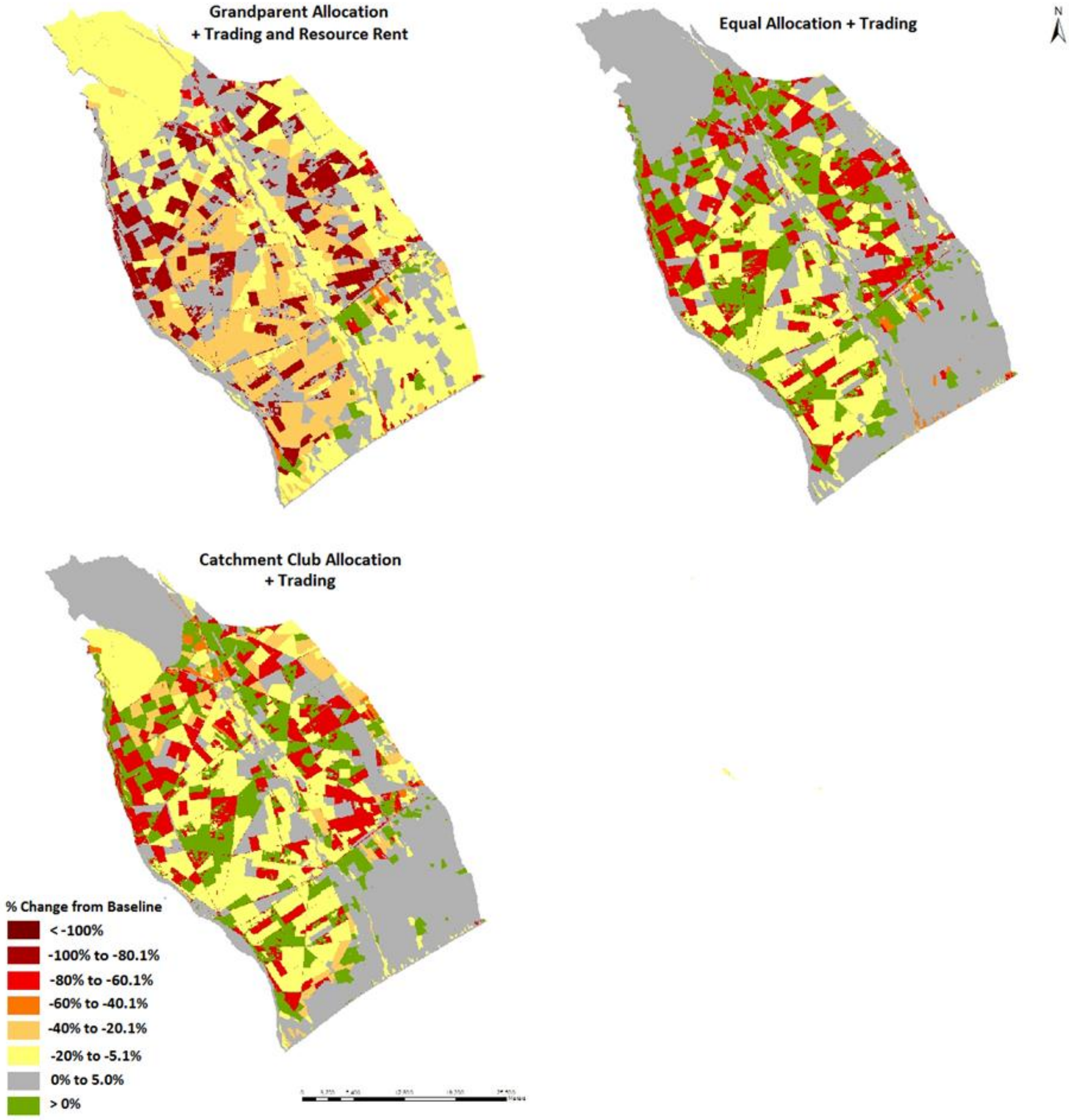


Figure 64: Percentage Change in Cash Farm Surplus ($/ha) from the Baseline




Grandparent Allocation
+ Trading and Resource Rent
Equal Allocation + Trading
N
Catchment Club Allocation
+ Trading
% Change from Baseline
< -100%
-100% to -80.1%
-80% to -60.1%
-60% to -40.1%
-40% to -20.1%
-20% to -5.1%
0% to 5.0%
> 0%

Appendix 4 – Additional Details on Mathematical Programming and NZFARM

Overview

The New Zealand Forest and Agriculture Regional Model (NZFARM) is a comparative static, partial equilibrium non-linear mathematical programming model of New Zealand forest and agriculture sector. Mathematical programming models have been widely used to model the interaction between agriculture production and the environment at farm, watershed, and sector level (Heckelei et al., 2012). The NZFARM methodology and calibration framework is based on the approach used for the US Department of Agriculture's Regional Environment and Agricultural Programming (REAP) model (Johansson et al., 2007).

The model was developed to assess impacts of policy and resource constraints on landowners. It was developed to provide insight on the relative impacts and trade-offs across a suite of policy scenarios (eg, cap with various allocation) or price impacts (eg, different degrees of nutrient or GHG taxes), rather than for explicitly modelling the absolute impacts of a single policy scenario. Parameterisation of the model often relies on biophysical and economic input data from several different sources. Therefore, the estimated impacts produced by NZFARM should be used in conjunction with other decision support tools to evaluate the 'best' policy to manage nutrients in the priority catchments.

NZFARM is calibrated so that optimality conditions are satisfied at observed levels of decision variables (eg, baseline land use and production matches input data). This is achieved using a methodology known as Positive Mathematical Programming (PMP) that has been proven to generate solutions with realistic diversification of production activities and smooth supply responses without adding weakly justified constraints to the model formulation (ie, model flexibility). PMP has been used extensively to calibrate agri-environmental programming models in the US and Europe (add some references here). The PMP approach is often used because its explicit representation of technology facilitates the integration of economic and biophysical models to produce more detailed estimates of impacts of policy on agriculture and forestry sector (Heceklei et al;, 2012).

To represent the substitution possibilities among land-uses enterprises, and farm management techniques, NZFARM calibration procedure uses a set of nested non-linear allocation functions, and farm management techniques. These allocation functions are based on technical and economic relationships for representative farm systems, and derived from neoclassical economic theory. The model is structured such that production practices can adjust to incentives based on changes to their net returns without placing bounds or flexibility constraints on their use. More details on agri-environmental mathematical programming models and the specifics of the NZFARM framework are discussed below.

Agri-Enviromental Mathematical Programming Models

Numerous features of mathematical programming models are useful in the analysis of interaction between agricultural production and the environment. First, the structure of these types of models is well suited for imposing resource and policy constraints while avoiding unrealistic discontinuities (eg, 'knife's edge') in the simulation solutions (de Frahan et al,. 2007). Second, the use of fixed-proportion production technology used in most programming models is appealing for its relative simplicity (Howitt, 1995). Third, the representation of production activities is consistent with the manner in which production systems are represented within biophysical models (Heckelei et al., 2012). Fourth, it is relatively easy to introduce new or alternative enterprises and management options even if there are few empirical observations. Fifth, programming models can be constructed from limited historical data and are thus able to handle some decision problems that econometrics cannot (de Frahan et al., 2007). Finally, programming models permit detailed analysis of the effects of policy changes across commodities, regions, and production systems.

As mentioned above, mathematical programming models are often parameterised using minimal empirical data. This is because existing data on the economic and environmental variables at the necessary spatial and temporal scale are generally limited, and the time and manpower needed to source and format additional data can be very time consuming. This is typically the case for parameterising NZFARM, particularly for key data such as spatially explicit enterprise area, farm management systems, and their effects on economic and environmental output.

The extension of programming models beyond farm or regional analysis has been limited by their inability to replicate observed patterns of production, often the result of the 'overspecialization' problem (Howitt, 1995; McCarl and Spreen, 1980; Preckel et al., 2002; de Frahan et al., 2007). Overspecialization most often occurs in linear mathematical programming models because the marginal rate of transformation among production activities is constant. This means that the rate at which the inputs can be switched from the production of one good to another does not change. Because the marginal rate of transformation among production activities remains the same regardless of the quantity of inputs already devoted to the production of a particular good, programming models will allocate all inputs to the production activity with the highest net return unless constrained by resource availability. In the case of New Zealand, this would typically result in too much land being allocated to enterprises that yield relatively high annual profits such as irrigated dairy and horticulture.

Before the development of currently employed modelling techniques, mathematical programming models typically relied on fixed technologies that necessitated the use of arbitrary upper and lower bounds on the activities to avoid overspecialization, referred to as flexibility constraints. Flexibility constraints often contain little technological or economic information, and model response is thus controlled by constraints that do not reflect limitations imposed by technology or economic behaviour. A proposed solution to the overspecialization or the calibration problem has been to specify cost functions for each production activity. A popular approach to date has been to use a method known as positive mathematical programming (PMP). With the PMP methodology, enterprise specific cost functions are created, which permits the degree of spatial and production disaggregation required for environmental analysis but eliminates the need to use flexibility constraints (Howitt, 1995).

The methodology used in NZFARM extends the general PMP formulation by nesting sets of nonlinear transformation functions under the PMP formulation. The use of transformation functions differ from flexibility constraints as, unlike flexibility constraints, they represent constraints imposed by our assumptions about the production technology. This approach builds on the foundations laid by both PMP and computable general equilibrium (CGE) modelling.

Our approach is similar to the technique used by Dervis et al. (1982) to specify country-specific export demand functions in CGE models in that it uses a functional form – a constant elasticity of transformation function – that can be specified by using prices, quantities, average costs, and an assumed elasticity of substitution. The approach also borrows from PMP as it uses shadow prices from calibration constraints to obtain the difference between average and marginal returns needed to specify transformation function parameters.

NZFARM uses empirical data of regional enterprise areas to construct a baseline that assumes that landowners determine the land use they desire, the enterprise that they will conduct on that particular land, and the management practices they will employ on the determined enterprise. In NZFARM, PMP functions are used to represent the positively sloping marginal cost curves for the land allocation decision at the soil type level. We then nest three sets of transformation functions under these PMP functions. The first set of CET functions allocates various land uses to each soil type. The second set allocates land use to the feasible enterprise areas. The third set of CET functions allocates enterprise areas to more detailed management options. This formulation results in a smooth response of enterprise areas to changes in relative returns among enterprises, in accordance with our neoclassical economic behavioural expectation of profit maximization. By using this approach, we avoid the problems of overspecialization and corner solutions that result from using linear activity analysis formulation. More details on the methodology employed in NZFARM are provided below.

NZFARM Optimisation and Calibration Procedure

The NZFARM objective function estimates the level of production outputs that maximize the net revenue[15] of production across the entire catchment area, subject to land use and land management options, agricultural production costs and output prices, and environmental factors such as soil type, water available for irrigation, and any regulated environmental outputs (eg, nutrient leaching limits) imposed on the catchment. Catchments can be disaggregated into sub-regions (ie, NZFARM zones) based on different criteria e.g. land use capability, irrigation schemes etc. such that all land in the same NZFARM zone will yield similar levels of productivity for a given enterprise and land management scheme. Total net revenue (π) in the catchment is specified in the model as:

$$Net\ Revenue\ (\pi) = \sum_{r,s,l,e,m} \begin{matrix} Output\ price * Output\ quantity \\ + Other\ gross\ annual\ income \\ -Livestock\ cost * Livestock\ input \\ -Variable\ cost * Variable\ input \\ -Annualized\ fixed\ cost \\ -Tax * Environmental\ output \\ -Land\ conversion\ cost * area\ converted \end{matrix} \tag{1}$$

The objective function is mathematically specified as:

$$Max\ \pi = \sum_{r,s,l,e,m} \left\{ \begin{matrix} PQ_{r,s,l,e,m} + Y_{r,s,l,e,m} - \\ X_{r,s,l,e,m}\left[\omega^{live}_{r,s,l,e,m} + \omega^{vc}_{r,s,l,e,m} + \omega^{fc}_{r,s,l,e,m} + \tau\gamma^{env}_{r,s,l,e,m}\right] \\ -\omega^{land}_{r,s,l} Z_{r,s,l} \end{matrix} \right\} \tag{2}$$

[15] Net revenue (farm profit) is measured as annual earnings before interest and taxes, or the net revenue earned from output sales less fixed and variable farm expenses.

where P is the product output price, Q is the product output, Y is other gross income earned by landowners (eg, grazing lease), X is the farm-based activity, ω^{live}, ω^{vc}, ω^{fc} are the respective livestock, variable, and fixed input costs, τ is an environmental tax (if applicable), γ^{env} is an environmental output coefficient, ω^{land} is a land-use conversion cost, and Z is the area of land-use change from the initial (baseline) allocation. Summing the revenue and costs of production across all NZFARM zones (r), soil types (s), land uses (l), enterprises (e), and management options (m) yields the total net revenue for the catchment.

The level of net revenue that can be obtained is limited not only by the output prices and costs of production but also by a number of production, land, technology and environmental constraints. Key land-management options tracked in the model include changing fertiliser regimes and stocking rates, adding an irrigation system or implementing mitigation technologies such as the installation of a dairy feed pad or the application of variable rate irrigation. More details on the specific land management, economic, and environmental factors tracked in the model are described below.

The production in the catchment is constrained by the product balance equation by a processing coefficient *(α^{proc})* that specifies what can be produced by a given activity in a particular part of the catchment:

$$Q_{r,s,l,e,m} \leq \alpha^{proc}_{r,s,l,e,m} X_{r,s,l,e,m} \qquad (3)$$

Landowners are allocated a certain level of irrigation (γ^{water}) for their farming activities, provided that there is sufficient available water (W) available in the catchment:

$$\sum_{s,l,f,m} \gamma^{water}_{r,s,l,e,m} X_{r,s,l,e,m} \leq W_r \qquad (4)$$

Land use in the catchment is constrained by the amount of land available (L) on a particular soil type in a given NZFARM zone:

$$\sum_{e,m} X_{r,s,l,e,m} \leq L_{r,s,l} \qquad (5)$$

and landowners are constrained by the their initial land-use allocation (L^{init}) and the area of land that they can feasibly change:

$$L_{r,s,l} \leq L^{init}_{r,s,l} + Z_{r,s,l} \qquad (6)$$

The level of land use change in a given NZFARM zone is constrained to be the difference in the area of the initial land-based activity (X^{init}) and the new activity:

$$Z_{r,s,l} \leq \sum_{e,m} \left(X^{init}_{r,s,l,e,m} - X_{r,s,l,e,m} \right) \qquad (7)$$

and we assume that it is feasible for all managed land uses to change with the exception of native forestland and tussock:

$$L_{r,s,native} = L^{init}_{r,s,native} \qquad (8)$$

In addition to estimating economic output from the agriculture and forest sectors, NZFARM also tracks a series of environmental factors including N leaching, P loss and GHG emissions. In the event that the central government or regional council regulates farm-based nutrient leaching or greenhouse gas emissions (γ^{env}) by placing a cap on a given environmental output from land-based activities (E), landowners could also face an environmental constraint:

$$\sum_{s,l,f,m} \gamma^{env}_{r,s,l,e,m} X_{r,s,l,e,m} \leq E_r \qquad (9)$$

Finally, the variables in the model are constrained to be greater or equal to zero such that landowners cannot feasibly use negative inputs such as land and fertiliser to produce negative levels of goods:

$$Y, X, L \geq 0 \qquad (10)$$

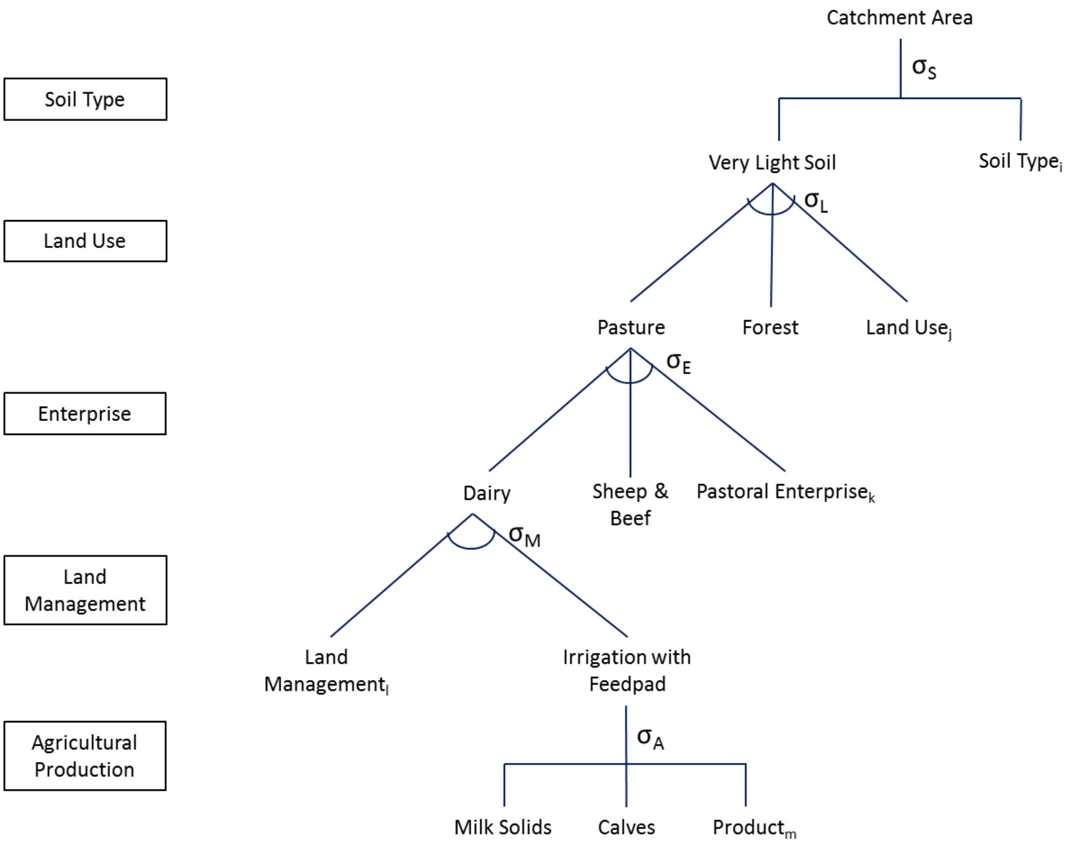
The 'optimal' distribution of soil type $s_{1...i}$, land use $l_{1...j}$, enterprise $e_{1...k}$, land management $m_{1...l}$, and agricultural output $a_{1...m}$ in NZFARM are simultaneously determined in a nested framework that is calibrated based on the shares of initial enterprise areas for each of the NZFARM zones. These initial (baseline) enterprise areas are usually obtained from a detailed land use map of the catchment, while the share of specific management systems are generated from a mix of farm surveys and expert opinion.

The key endogenous variable in NZFARM is $X_{r,s,l,e,m}$, the physical area for each of the feasible farm-based activities in a catchment. In the model, landowners have a degree of flexibility to adjust the share of the land use, enterprise, and land management component of their farm-based activities in order to meet an objective (eg, achieve nutrient reduction target at least cost). Important exogenous variables include commodity prices, environmental constraints (eg, nutrient cap), water available for irrigation, and technological change. Unless specified, these exogenous variables are assumed to be constant across policy scenarios.

The allocation of farm activity area is specified in the model through the use of constant elasticity of transformation functions (CET). The CET function essentially specifies the rate at which regional land inputs, enterprises, and outputs produced can be transformed across the array of available options. This approach is well suited for models that impose resource and policy constraints as it allows the representation of a 'smooth' transition from across production activities while avoiding unrealistic discontinuities and corner solutions in the simulation solutions (de Frahan et al., 2007).

At the highest levels of the CET nest, land use is distributed over the NZFARM zone based on the fixed area of various soil types. Land use is then allocated between several enterprises such as arable crops (eg, process crops or small seeds), livestock (eg, dairy or sheep and beef), or forestry plantations that will yield the maximum net return. A set of land management options (eg, good management practice bundle, reduced fertiliser regime, etc.) are then imposed on an enterprise which then determines the level of agricultural outputs produced in the final nest. Figure 65 shows the potential nest for an irrigated dairy farm in New Zealand that has a feed pad and produces a several outputs from pasture grown on very light soil.

Figure 65: An Example of the Structure of CET Function Nest in NZFARM



The CET functions are calibrated using the share of total baseline area for each element of the nest and a parameter, σ_i, where $i \in \{s, l, e, m, a\}$ for the respective soil type, land use, enterprise, land management, and agricultural output CET elasticity parameters. These CET elasticity parameters can theoretically range from 0 to infinity, where 0 indicates that the input is fixed, while infinity indicates that the inputs are perfect substitutes (ie, no implicit cost from switching from one land use or enterprise activity to another).

The CET function is nonlinear, which implies that the marginal rate of transformation between land used in one enterprise activity under a particular management system and land used for another enterprise system under a specific management system is declining. The parameters for these equations are derived from the area of each farm level activity in the baseline ($X_{r,s,l,e,m}$), the net return to each activity ($\pi_{r,s,l,e,m}$), and an elasticity of transformation (σ_e). Net returns for each activity are obtained from shadow prices on calibration constraints that are placed on the objective function (equation 1).

The enterprise-level CET function is mathematically represented as:

$$RAC_{r,s,e} = \alpha_{r,s,e} * \left[\sum_{r,s,l,e,m}\left(\delta_{r,s,e} * X_{r,s,l,e,m}\right)^{-\rho_e}\right]^{-\left(\frac{1}{\rho_e}\right)} \quad (11)$$

where $RAC_{r,s,e}$ is the area of enterprise e under management system m, and $\delta_{r,s,e}$ is the CET allocation parameter for enterprise area e on land use l and soil type s in region r, specified as:

$$\delta_{r,s,e} = \frac{\pi_{r,s,l,e,m} * X_{r,s,l,e,m}{}^{1+\rho_{r,s,e}}}{\sum_{r,s,l,e,m}(\pi_{r,s,l,e,m} * X_{r,s,l,e,m})^{1+\rho_{r,s,e}}}, \quad (12)$$

$\pi_{r,s,l,e,m}$ equals the net return per hectare for each enterprise that is derived from the shadow value of constraints placed on the allocation of enterprise activities in each region,

ρ_e is the CET substitution parameter estimated based on the CET elasticity parameter σ_e:

$$\rho_e = \frac{1-\sigma_e}{\sigma_e} \quad (13)$$

and $\alpha_{r,s,e}$ is the enterprise CET scale parameter that is based on the share of one unit of that enterprise activity e on soil type s in region r:

$$\alpha_{r,s,e} = \frac{RAC_{r,s,e}}{\left[\sum_{r,s,l,e,m}(\delta_{r,s,e} * X_{r,s,l,e,m})^{-\rho_e}\right]^{-\left(\frac{1}{\rho_e}\right)}} \quad (14)$$

The mathematical formulation for the land use and management-level CET functions are similar to the enterprise-level CET function.

The transformation elasticity values in NZFARM are assumed ascend with each level of the nest between land use, enterprise, and land management. This is done to represent that landowners typically have more flexibility to transform the mix of management and enterprise activities compared with altering the share of land use or to shift land use across soil types, as observed empirically (Johansson et al., 2007; Kerr and Olssen, 2012; Li et al., 2012). For this version of NZFARM, the CET elasticities are specified as follows land use (σ_L= -2), enterprise (σ_L= -3), and land management (σ_L= -20). A large CET elasticity was imposed on the land management nest to simulate that most landowners are highly likely over the long term to employ new management technologies on their existing enterprise to meet environmental constraints rather than change land use. A lower elasticity value would indicate that they are relatively less responsive to implementing a management change and thus may be more willing to change their land use instead to meet the environmental constraint. The CET parameter for soil (σ_S) is set to be 0, as the amount of a particular soil type in a NZFARM zone is fixed. In addition, the parameter for agricultural production (σ_P) is also assumed to be 0, implying that a given activity produces a fixed set of outputs.

NZFARM is programmed and maintained in the modelling software package General Algebraic Modelling System (GAMS), and the baseline calibration and scenario analysis are derived using the non-linear programming (NLP) version of the COIN IPOPT solver (GAMS 2011). The model typically takes less than 5 minutes to calibrate the baseline and conduct a single policy scenario. The most time-consuming aspect of using NZFARM is collecting and verifying the large amount of economic and biophysical data that is required to represent the farm activities adequately in the model.

Finally, NZFARM was originally developed as a comparative static model to estimate the relative difference between a baseline and policy scenario at between two points in time (ie, before and after). It can also be formatted to run as a myopic or recursive dynamic model with 5- or 10-year time steps. In the recursive dynamic case, the optimal solution from each time step is used to 'recalibrate' the model before simulating the next step in time. Under this relatively simple approach, the model is structured such that the economic agents only respond to the 'state' of the world at that particular time period and are not able to foresee changes in environmental policy, market prices, or climatic conditions in the future.

The model baseline is parameterised and calibrated using a number of steps. The calibration procedure is as follows:

1. Load production and economic data into NZFARM. Key data include production and environmental output coefficients, production costs and output prices.

2. Load enterprise area from land use map into NZFARM. The area is multiplied by the coefficients specified in (1) to estimate total net revenue, total production and total environmental outputs

3. Specify CET elasticity parameters for land use, enterprise, and land management allocation functions. This will establish the 'flexibility' of landowners to adjust their land use and land management under different economic and environmental conditions.

4. Run NZFARM with CET allocation procedure. This will create the baseline outputs and shadow prices based on constraints applied to the objective function that all policy scenarios are measured against.

5. Verify that calibrated enterprise area and outputs are similar to the input data. This ensures that optimality conditions are satisfied at observed levels of decision variables.

6. Verify that model produces responses to general policy shocks that are logical and consistent with economic theory.

Note that with the last step, we cannot always use empirical evidence to 'calibrate' or 'validate' the model to ensure it is correctly mimicking what is happening in reality. This is because a nutrient limit in the catchment has not taken place yet. Instead, we can at least 'test' the model to see if it responds in a logical and consistent manner to the anticipated 'shocks' on landowners in the catchment. For example, it is assumed that landowners who have to reduce N leaching from their farm would, on average, implement a change in farm-level activities that minimises their reduction net revenue relative to the baseline, and that the impacts of these changes should increase as the restrictions become larger. It may also be possible to run NZFARM using shocks that have occurred in the catchment in the past, provided that data and information are available. These include changes in commodity prices, the implementation of a Forestry Emissions Trading Scheme (ETS), or addition of a new irrigation scheme.

The NZFARM policy scenarios procedure is as follows:

1. Run baseline calibration procedure. This will estimate the baseline conditions against which all policy scenarios are measured.

2. 'Shock' model by changing input costs, output prices, or adding environmental constraint (eg, cap on nutrient leaching).

3. Run NZFARM in policy scenario mode to maximise net revenue subject to 'shocks' and model constraints. The model will estimate changes in enterprise area and land management relative to the calibrated baseline, which will have an impact on the level of economic and environmental outputs produced.

Estimated changes in enterprise area from the baseline are often correlated with the relative share of area utilised by a particular enterprise and management activity in the baseline as well as the relative profits or net revenues. That is, NZFARM is parameterised with the nest of CET functions, so that it will not switch from a highly profitable enterprise in the catchment such as irrigated dairy into a less productive land use such as scrub. This is particularly the case if there is already minimal scrubland in the baseline, as that implicitly signals that scrub currently is not a preferred option for most landowners in the catchment. A notable exception would be that the policy shock is so large there must be significant changes to less productive land use to obtain a feasible solution.

The NZFARM model literally produces thousands of outputs. Key outputs include net revenue, cash farm surplus, N leaching, P loss, GHG emissions, irrigated area, and commodities produced. These can be sorted and listed using any combination of the initial indices: NZFARM zone (*r*), soil type (*s*), land use (*l*), enterprise (*e*), and management option (*m*). Outputs are listed as estimated value as well as relative change from the calibrated baseline.

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